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Institute and Related Activities

Control of Gaseous Conduction

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Review of the Subject.—*In electric circuits of all sorts, power is transmitted principally by metallic conductors. In order to control the flow of power, or to convert it from one form to another, the constants of the circuits are varied. The connections of the metallic conductors may be altered for this purpose; but on high potentials this operation is attended with difficulty. The rapidity and ease of control are also limited.*

For this reason there has been a tendency, in recent years, toward the increased use of control devices employing non-metallic conduction and these are now being rapidly brought to the fore. As examples we have the very versatile thermionic tube and the mercury arc rectifier. The former has received particular attention of late.

Devices employing conduction by gaseous ions have been handicapped in this general evolution by three main disabilities: the first being the difficulty of placing the discharge where wanted, the second, the tendency of the working gas to disappear, and the third, decidedly erratic action. These disabilities have recently been to a large extent removed by the advent of a principle called the "short path principle", by which discharge can be prevented except where wanted. This has also led to long life, for by placing the discharge in proximity only to certain porous materials, gaseous clean-up and disintegration are both prevented. With this change, uniformity of action also appears.

By utilizing this principle, gaseous conduction devices may be designed, for example, as rectifiers. Two examples are described, the first obtaining unilateral characteristics by the use of a magnetic field, and the second by the use of a space charge.

The present models, as described are capable of handling only small amounts of power; but there is no inherent limitation in this direction. The usual conditions of cost, reliability, life and so on will determine development for higher powers.

It is impossible to predict at present the particular portions of the electrical field in which this device in its various forms will find a use. The authors believe, however, that engineers will find its possibilities of interest.

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I. Classification

THERE is a very noticeable tendency in present-day electrical engineering toward the use of control devices which may be generally specified by stating that they involve non-metallic conduction. It is difficult to control the flow of current in a wire by any control device which does not actually separate the metallic circuit. A small amount of control can be obtained by magnetic fields, but this is entirely inadequate for most power purposes. On the other hand, the flow of current through devices which involve other types of conduction may be much more readily controlled by external means. This gives rise to a host of devices, for the control of current makes possible the construction of rectifiers, amplifiers, and the like.

In present-day power engineering there is great need for better rectifiers for railway work and so forth, and for better control devices for handling in reasonable space the large voltages and currents necessary in extensive power systems. Undoubtedly the next few years will see a rapid development of devices for these purposes. The probability is that much of this development will occur along the lines of non-metallic control.

Devices which utilize non-metallic conduction may be readily classified according to the nature of the carriers of electricity which are employed.

1. Devices employing ions in a liquid or semi-solid: Insulators which become conducting because of high temperature and electrolytes in general involve this type of conduction. Such conduction is always accompanied by chemical action. No devices involving this type of conduction have become commercially important as rectifiers or the like. The aluminum lightning arrester is an example of a protective device operating on this basis.

2. The simplest type from a theoretical standpoint is that in which electrons only are used. The device then consists of a container exhausted to a hard vacuum, with two or more electrodes, one of which is a source of electrons. Such a device is the thermionic tube, the most important single piece of apparatus which has appeared in electrical engineering in twenty years. In addition to the thermionic tube, various other similar arrangements have been suggested in which the supply of electrons is obtained without utilizing an incandescent member, as for instance by the use of the photo-electric effect. None of these latter are at present commercial.

Devices under this classification are characterized by somewhat severe current limitations. The internal drop is very variable, and is determined by space charge effects. They are capable of operating at very high potentials.

3. Devices employing electrons, and gaseous ions:

(a) Under this heading we have first the device which employs a hot filament in a gas-filled receptacle. Such for instance is the Tungar rectifier. This device conducts relatively large currents, for it employs gaseous conduction as well as conduction by means of the primary electrons evaporated from the filament.

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It is, however, unable to withstand large reverse potentials.

(b) Under this heading there have been second many devices in which the supply of electrons is obtained in other ways than by heating a filament. The principal way is to remove them from a cold metal electrode by positive ion bombardment. The old "Geissler" tube operates in this manner. So also does the gaseous X-ray tube. Such devices offer great possibilities, but have not heretofore become important commercially as control devices on account of difficulties which will be treated below. Under this heading comes the device which is the subject of the present paper, and this class will be further analyzed.

4. There are also devices in which the carriers are electrons, gaseous ions and charged metallic vapor. This includes all sorts of arcs. The mercury arc rectifier comes under this heading; and as an example of its use as a control device, the Vreeland oscillator.

This type of conduction is accompanied by rapid vaporization of the electrodes. The part played by the vapor in the conduction is still a matter of doubt. The material of the electrodes is transferred and lost, so that it must be continually replaced. In mercury arc devices this replacement is made automatic. Devices of this type are characterized by low internal drop, and the current capacity limited only by the cooling means employed. In voltage they are limited to that potential which will cause ionization of the working gas and conduction from the cold electrode.

II. Analysis of Type 3 (b)

The type of device employing electrons and gaseous ions in which the electrons are obtained by bombardment, has many desirable features. First, the current which can be passed through such a device is limited only by the capacity of the cooling means employed to dissipate heat. For short intervals there is hence practically no upper limit to the amount of current which can be passed between the electrodes. This is in contrast to the thermionic device, in which the upper limit of current is dependent upon the number of electrons which can be evaporated from a filament. In this respect the gaseous conduction device and the arc are similar.

Second, there is not necessarily involved any part at very high temperature. This greatly simplifies design and removes one limitation to the life of the device.

There is no inherent reason that disintegration of electrodes should accompany gaseous conduction proper. Where disintegration enters in such a device it is incidental and avoidable; for the operation does not depend upon and is not necessarily accompanied by disintegration. This feature is in direct contrast to both the thermionic tube and the arc. In the former the filament, in order to emit electrons copiously must unavoidably operate at such temperature that molecules of the material of the filament also evaporate to some extent. The filament life is thus directly connected with the quantity of electricity passed through the tube. In the arc the wasting of the electrodes is also intimately involved in the mechanism of conduction, and is here much more rapid; although it can be avoided in the mercury arc, and to a lesser extent in other arc devices, by provision for replacement.

On the other hand, gaseous conduction devices have always in the past been subject to very decided limitations.

First, the voltage which could be employed has been limited by the gas pressure used. In this respect there has been for this type of unit, in common with the arc a serious disadvantage as compared to the thermionic tube. The disadvantages ordinarily present in this class of device in general, and this disadvantage in particular, are treated in detail in this paper.

Second, the internal drop is in general of necessity higher than in the arc. A comparison of internal drop with that of the thermionic tube is hardly possible, for the gas tube involves a drop nearly independent of the current, while the exact opposite is true of the thermionic device.

Third, gaseous conduction devices have been uniformly erratic in action. The reason for this will be brought out below. On this account, knowledge of the theory of gaseous conduction has been delayed, and experimenters have been repelled from this field. The limitation is not inherent, but has always been present.

Fourth, this class of apparatus has been liable to short life on account of a change in the nature or pressure of the gas employed, or due to a variation in the electrode surface. This last disadvantage is decidedly avoidable, but it has been the principal obstacle in the past to development along these lines.

This paper is devoted to the brief exposition of a development by which the disadvantages of this type of device have been largely overcome. By removing the difficulties, the way has been prepared for a number of applications of the principles of gaseous conduction. One of these applications is described sufficiently to render the use of the principles apparent.

III. The Short Path Idea

The first limitation was in the working voltage (or the back voltage in a rectifier) which could be employed. In the ordinary gas tube this is limited to that voltage which will cause ionization of the gas and release of electrons from the electrodes by bombardment at times when the device should really be insulating. There has been recently developed a principle which allows of the use with the gas conduction tube of voltages far in excess of this limit.

This principle is properly called the "short path principle". It is the outgrowth and extension of an observation which has long been noted by physicists. It allows of the use of high back-voltages by not giving them opportunity to produce ionization.

It has long been known that if two electrodes are situated in a gas of a pressure such that their distance apart is comparable with the mean free path of an electron in the gas, a discharge will pass between them by long paths in preference to shorter ones. If two electrodes are spaced close together in a large bulb in a properly attenuated gas, the discharge between them will prefer the long path from the back of one electrode clear around to the back of the other, the short direct path remaining dark. It has not been generally recognized how strong is this preference, or that it could be utilized to advantage. The short path idea extends this principle by suppressing the long path entirely. If we so construct the device that *all* paths between the electrodes available for discharge are short, the device will stand large voltages and carry practically no current. All paths may be rendered short, as above defined, either by placing the electrodes close together or by placing obstructions in the way of the discharge. The diagram of Fig. 1 will show one manner in which this can be accomplished. It will be noted in this diagram that, if the electrostatic field between the electrodes be mapped out, all lines of electrostatic force are either short or are interrupted by the glass of the containing tube in such manner that the path available for discharge is short. When a potential is applied to such a device, there is no conduction even far above the potential at which the device would break down if the electrodes were widely separated, or the gas pressure high. As an illustration of this statement, a device constructed as above with clean electrodes and pure gas, with a spacing of one millimeter and a pressure of two millimeters of helium, will withstand continuously 10,000 volts and pass an amount of current which is hardly measurable. With the electrodes several centimeters apart, this same tube would have broken down at perhaps 300 volts, and at 500 volts applied would have carried several hundred amperes, if the external circuit would allow, and would probably have been destroyed. It should be noted carefully, however, that in order to render the unit thus insulating, under conditions where widely spaced electrodes would break down, it is necessary that *all* paths available for conduction be short.

By properly utilizing this principle, the voltage limitation of the gaseous discharge type of conduction is largely removed.

IV. First Application of the Short Path Idea

The short path idea also removed the third limitation. It can render a gaseous conduction device stable and reproduceable instead of erratic in action.

Gaseous conduction devices have in the past almost always been constructed in glass tubes and with the diffuse discharge intimately in contact with the glass. Such construction is sure to lead to erratic behavior. Due to the ionization, the glass is bound to accumulate charge, which will vary rapidly with the nature of the discharge, the temperature of the glass and a number of other factors. These charges vary the electrostatic fields present, and modify the conduction in a sudden and arbitrary manner. Due to this factor alone, such devices have gained an undesirable reputation as regards unreliability of action. It is evident that in order to remove difficulty in this regard, the discharge must be confined to a part of the device remote from any insulator.

This can now be accomplished. By the short path idea, ionization is prevented everywhere in the device except in one region where the paths are left long or are rendered so. This region is located far from any insulators. Charges therefore cannot accumulate. The resulting discharge is steady.

One means of arranging matters is shown in Fig. 2. The tube here shown is similar to the insulating tube of Fig. 1, except that one of the electrodes is made hollow and a central opening to this hollow space is provided. Between the electrodes in the center there are hence long paths. So when a potential is applied,

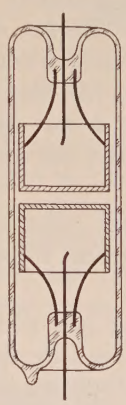

Fig. 1

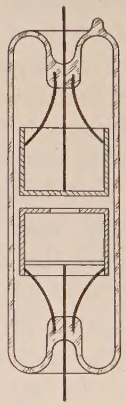

Fig. 2

a discharge can occur in this central region and nowhere else. Such a discharge is remote from the glass of the tube or from any other insulator. It is thus not affected by parasitic charges, and is steady in accordance with the circuit conditions.

As an example of this steadiness may be mentioned a tube carefully constructed along the lines shown in Fig. 2. A current of about ten milliamperes was passed through this tube from a storage battery source. A pair of high-resistance telephones placed in series with the tube gave no sound. In fact the variations in current were amplified by a two-stage thermionic amplifier before becoming barely audible. This is in decided contrast to the result which would have been obtained had the electrodes been widely separated and the discharge in proximity to the glass walls.

Nearly all of the study which has been made of the laws governing gaseous discharge has utilized glass-walled tubes with the discharge in proximity to the glass. To this fact may be attributed much of the present lack of complete knowledge of these laws.

V. The Maintenance of Gas Pressure

The same control of the discharge which is used to render it stable may at the same time be used to avoid

the last disadvantage mentioned in the analysis. This limitation involved the disappearance of the working gas.

The variation in pressure which occurs in the usual gaseous conduction apparatus has long been a source of difficulty. It was one of the principal drawbacks of the gaseous X-ray tube; and it has to a large extent prevented the rapid development of gaseous discharge illumination.

When a discharge is passed through the ordinary gaseous discharge tube, the nature and pressure of the gas continually change. Of course when the working gas is chemically active, the disappearance is readily accounted for. Even when using an inactive gas, such for instance as helium, a variation in pressure will occur. There will, for one thing, be a variable amount of gas occluded on the walls of the container, but the change in pressure from this cause is small when any fair-sized amount of gas is present. In addition, however, there is a continual and really serious disappearance of the gas due to another phenomenon entirely. In order to make a gaseous device of long life, this effect must be avoided. This disappearance is not due to chemical action, as it continues even when the working gas is chemically inactive.

A study, made possible by short path control, has determined the action of this second cause of disappearance and has found a remedy.

The action of clean-up of a working gas which is chemically inactive is usually accompanied by disintegration. In any case the presence of disintegration greatly increases the rapidity with which the working gas disappears. The amount of gas which can be removed from a vessel in this manner is truly surprising. By passing a discharge between aluminum electrodes in a half-liter vessel, for example, the gas pressure of helium has been reduced from seven millimeters to practically zero in a few hours' time. In fact, quite a hard vacuum may with care be produced in this manner.

Apparently gaseous discharge is accompanied by a penetration of the impacting positive ions into the cathode. The distance to which they can penetrate in this manner must be extremely small, under ordinary conditions of the order of magnitude of one-ten-thousandth of an inch. Yet very large volumes of gas may thus disappear. If we compute the gas pressure produced in this manner at the surface layer of the electrode material, it is found to be enormous. This possibly forces gas further into the interior of the metal progressively. It also results in minute explosions which project small particles of the metal from the electrode at high velocity. This is at least part of the mechanism of electrode disintegration. This disintegration is accompanied by gas disappearance.

One or two observations will tend to throw light on the above statements. First, the gas which disappears in this manner can be in great part recovered by heating the electrode material to near its fusing point, thus apparently offering the imprisoned gas opportunity to escape. The temperature necessary for recovery therefore depends upon the material of the electrodes. This has been accomplished with several different materials.

Another observation is more striking. A tube was constructed as shown in Fig. 3. In one electrode was located a small volume of pure tin. In fact the lower electrode, of iron, was coated all over inside with the tin. The discharge is confined by reason of the short path principle to such space that one electrode is in effect entirely of tin. The device was also constructed so that during discharge the surface of the tin could be observed by means of a low-power microscope. The tube was then operated at a current such that the electrodes became sufficiently warm to render the tin molten. Under these conditions a very interesting phenomenon was observed. Small bubbles appeared on the surface of the tin, gradually increased in size and finally burst. The bursting was accompanied by the projection of a small amount of metallic tin at fairly good velocity. Some of these bubbles were large enough to be observed with the naked eye, although their size depended naturally on the temperature and hence the viscosity of the tin. Moreover, it was observed that with the discharge thus confined to tin electrodes in this molten state, there was no change of the pressure of the working gas over long intervals of time of discharge. Intervals were studied of several thousand hours and with 100 or 200 milliamperes flowing. It thus becomes very apparent that disintegration and gaseous clean-up go together. Also that by proper construction, difficulties of this nature can be entirely avoided.

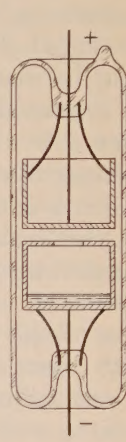

Fig 3

As an additional method of attack, it has been noted that a discharge maintained in proximity to carbon, and to nothing else, will not result in a disappearance of the working gas, provided the carbon is of proper grade and the working gas is chemically inactive. This is also true of some other materials under definite limitation as to allowable voltage drop and so on. The use of carbon, however, will serve as an excellent example. Apparently carbon does not disintegrate appreciably under a discharge of reasonable voltage drop, for tubes with carbon electrodes operated over periods of several thousand hours showed no measureable change in the carbon surface. This is due undoubtedly to the porosity of the carbon, which prevents a gas pressure from accumulating. Carbon will not hold the working gas imprisoned.

There is still room for a great deal of investigation

on the subject of gaseous clean-up. The above procedure will enable us, though, to construct devices of this nature in which any limitation of life due to disintegration, or loss of working gas, is entirely avoided as far as can be determined from tests extending over more than 6000 hours on two of the specific constructions outlined.

VI. Magnetically Controlled Tubes

By utilizing the above principles, we now have available a type of gaseous discharge device which is capable of withstanding a high voltage, which is stable in operation and which is of long life. There is immediately a large number of ways in which such a device may be controlled and utilized. One of these and its application will be described in the present

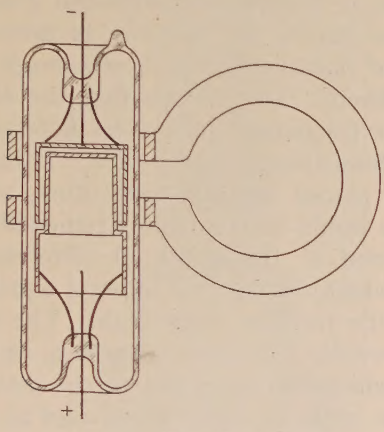

Fig. 4

paper. In a previous paper[1] has been described a different form, which need here only be mentioned.

In the form of device described in the previous paper a construction is utilized such as is shown in Fig. 4. The electrodes consist of two concentric cylinders. The gas pressure employed is such that the distance apart of the cylinders is short compared to the mean free path of an electron in the gas. *All* paths between the electrodes are rendered short by the construction shown. Under these conditions the device insulates for a fairly high potential applied in either direction.

Provision is made, however, for the introduction of a magnetic field which is nearly axial in the space between the electrodes. This is accomplished by means of a permanent magnet and pole pieces, as shown, whereby the field is conducted to the space where it is desired. Without the presence of the field, the flight of electrons between the cylinders is radial. By the action of the field, these paths are curved. A curved path between the cylinders is long compared to the direct radial path. Accordingly the device may be so arranged that, with the field present, the electron paths are long enough to cause cumulative ionization and consequent conduction, whereas without the field we have complete insulation.

1. *Proceedings* of Inst. of Radio Engineers, February, 1922.

Under these conditions the strength of field necessary for conduction with the inner cylinder negative is greater than that for conduction with the outer cylinder

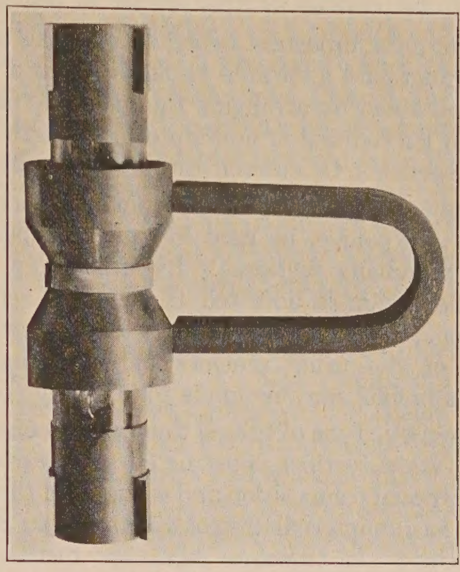

Fig. 5

negative. In fact, the ratio of the two critical fields is the same as the ratio of the cylinder diameters. This relation, which was first derived from the mathematics of the electron paths, has been checked by experiment. Accordingly, by utilizing a field strength intermediate between these two values, a device may be produced

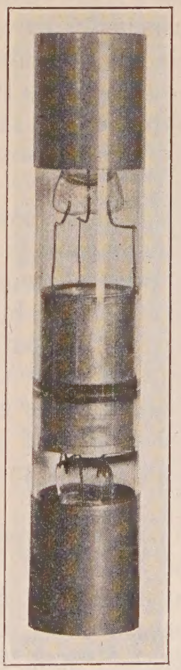

Fig. 6

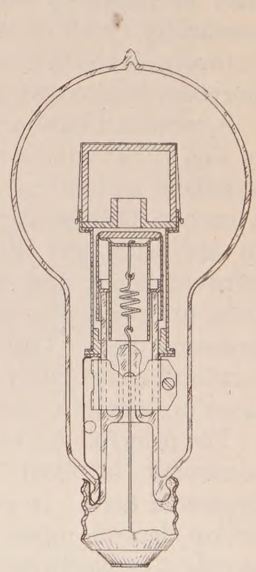

Fig. 7

which will conduct in one direction only; that is, a rectifier.

Illustrations of a tube of this type are shown in Fig.

5 and Fig. 6. The magnet and pole pieces are removed in Fig. 6 in order to show the construction. It will be noted that the tube is made cartridge type, with ferrules to be inserted in clips similar to fuse clips.

Certain quite important benefits as regards allowable voltage range and allowable variation of field strength may be obtained by arranging the magnetic field to be somewhat curved and of non-uniform strength. These matters need not be entered into at the present time.

The above method of control, by means of a magnetic field may, of course, be used for other purposes than that of producing rectifiers. By utilizing a tube in which the design is adjusted to render it critical to field strength, an amplifier may be produced. Also, by any of the usual schemes of "coupling back," such an amplifier may be made to act as an oscillator.

The magnetic type of tube is thus capable of a variety of uses. As a rectifier constructed with carbon electrodes of special composition and with one of the inactive gases, it has an internal drop of about 150 to 200 volts. The efficiency is therefore high on rectification of voltages of a few thousand. The current which can be passed through such a tube is limited only by the amount of heat which can be dissipated from the surface of the tube. Hence its power output is limited only by its design, and not by any inherent current or voltage limitations.

VII. Hollow Cathode Type of Rectifier

There are other types of control possible besides magnetic control. One of these is to use a space charge effect, the space charge being due principally to the positive ions. By the use of this principle, rectifiers may be produced which, while they do not have the versatility or all of the power possibilities of the manetically controlled tube, are yet preferable for some purposes on account of simplicity.

A cross-sectional diagram of one such tube is shown in Fig. 7. It will be noted that the cathode consists of a hollow carbon cup. The anode consists of simply a carbon button placed directly in front of the hole in the cathode. By the use of shields, all paths between anode and cathode, except those through the hole, are rendered too short for conduction at the gas pressure used. There is no magnetic field, and no auxiliary control device of any sort. Only two connections are made to the tube.

The principle by which this device operates is somesomewhat involved. A brief outline only will be presented here. In general, it may be stated that the action depends upon the wide difference between the mobility of electrons and positive ions, and upon the accumulation of a positive space charge.

When the device is conducting current, the space inside the cathode is filled with ionized gas, that is with a cloud of electrons and positive ions. It is due to the presence of these, and to their wandering toward the anode and cathode respectively, that conduction takes place. At any given instant, however, there will be a very great preponderance of positive ions. This is due to the much greater mobility of the electron. The charges on electron and singly ionized positive ion are equal. Their masses are, however, in the ratio of one to several thousand, the exact ratio depending upon the nature of the gas used. Accordingly under a given applied potential gradient, the electrons as they are freed acquire velocity and move out of the field with much greater promtitude than the positive ions. The slow-moving, heavy ions are left behind. Accordingly we have ordinarily in gaseous conduction devices, during conduction, in the space between anode and cathode a positively charged cloud.

Due to the form of the electrodes in the hollow cathode type of *S*-tube, the potential gradient in the hollow space inside the cathode is normally small. The cloud of positive ions is hence swept out of the field only slowly. Due to this fact the cloud is not cleaned up or discharged during the half-cycle in which no current flows through the device. If the electrodes were simply placed opposite each other, any cloud of positive ions would be completely removed during this inactive period if the potential difference between electrodes, which during this interval equals the back voltage on the rectifier, were high. The hollow construction prevents this from occurring, and the cloud of ions on which the operation of the device depends persists from cycle to cycle, when used at commercial or higher frequencies.

Refer to the simplified diagram of Fig. 2 for convenience. When the hollow electrode is negative, the tube conducts freely. Under these conditions positive ions are dropping from the cloud onto the interior surface of the hollow cathode, where they liberate electrons. These electrons proceed toward the anode, and on their way ionize neutral gas molecules and form new positive ions, so that discharge is maintained. The original electrons and those formed by ionization nearly all pass out sooner or later through the hole in the cathode, and thus reach the anode; which latter for this direction of conduction is the solid electrode. This they can do rapidly and with facility on account of their great mobility, which allows them to attain speed quickly. Thus conduction in this direction occurs with facility.

Consider now, however, that the potential is applied in the reverse direction, the solid electrode being now the cathode. Positive ions under this condition will wander out from the hollow space, through the hole, and impinge upon the solid cathode. Their progress for most of their journey is, however, painfully slow; for they are large and heavy and the gradient of the field up inside the cloud is extremely weak. Nearly all the potential drop, because of the geometrical construction and the space charge effect, occurs out in the region between the electrodes. Practically the only ions acted upon by the potential are those near the

exit. When an ion reaches here it speed up, drops into the cathode, and there may release an electron. This electron flies back into the cloud, and possibly produces ionization. The current that can pass is, however, limited to that produced by the number of ions arriving at the cathode; and this, on account of the conditions, is very small for potential in this reverse direction.

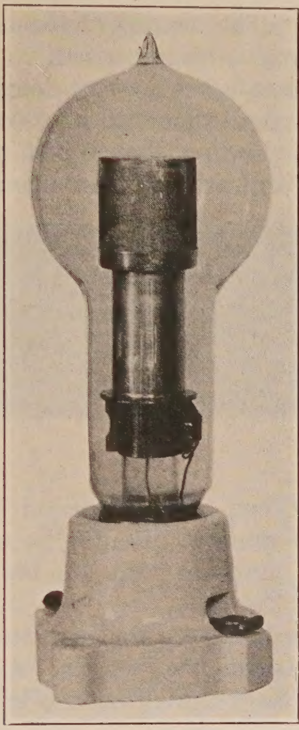

Fig. 8

For potentials in the conducting direction, the cloud of ions forms practically an extension of the anode projecting up into the hollow space inside the cathode. A large area is available, and a steep gradient, to pull ions over to the cathode and cause conduction. For a potential in the reverse direction, the cloud of ions serves again practically as an extension of the anode, in this case the hollow member, but now it acts effectively to plug up the hole in this electrode and render all possible paths for conduction substantially short. The area acting is small, and very few ions are pulled to the cathode to cause current.

The ratio of currents for the same applied potential in the two directions, when that potential is sufficient to cause conduction at all, is much greater in the working range than the ratio of the two cathode areas; the first being the inside area of the hollow electrode, and the second the projection of the hole onto the solid member. The ratio is much greater, for in one case conditions are correct for building up cumulative ionization and in the other case they are not.

There are secondary additional actions going on, such as recombination etc., which complicate the analysis. For example, when the tube is first started, there is a transient period during which the cloud of ions is being built up. The above does not pretend to be complete, nor entirely rigorous. It will, however, give some idea of how such a hollow cathode device, controlled by the presence of a space charge, utilizes the short path principle for rectification.

Tubes constructed in accordance with this principle are shown in the illustrations Figs. 8 and 9, and in section in Fig. 7. These tubes are constructed for low-power service where simplicity and long life are essential requirements. All that is necessary in order to connect them into circuit is to screw them into the ordinary lamp socket. Of course where higher potentials are desired, the socket must be made special in order to properly withstand the voltage.

This tube is exactly the same in principle as the simplified tube of Fig. 2. The additional parts employed are for several purposes. It is now being produced for engineering use, is arranged to be mounted on a single stem, which makes for accuracy and ease of assembly. Both leads are brought out from the same end, which is convenient in moderate voltage service. The working parts are far removed from the glass bulb, which avoids danger of overheating the glass. There is a considerable volume of reserve gas, which avoids sudden changes of gas density due to temperature effects.

The tube of Fig. 8, as now supplied commercially, has a rated capacity of 50 milliamperes, and is designed to be used for supplying 500-volt direct current. In both of these matters it has some overload capacity. This particular tube was designed for the use of amateur

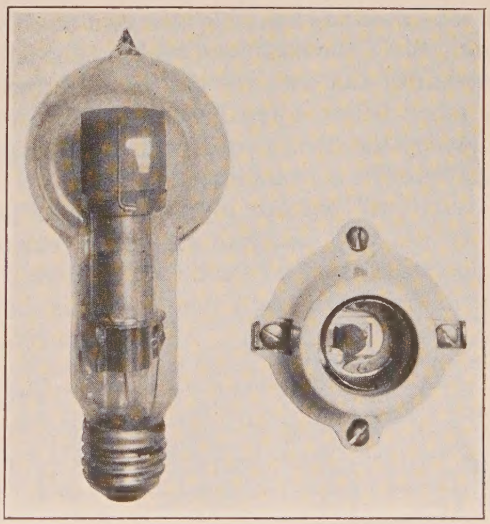

Fig. 9

radio enthusiasts for supplying plate voltage for use on their thermionic tube generators. It is also useful for charging small storage batteries, for fire alarm systems, and so on.

The behavior of this tube is shown by the characteristic in Fig. 10. This characteristic is taken on a continuous potential circuit. It is rising throughout

the working range, although nearly flat, and not drooping as is that of the arc. It differs considerably from the dynamic characteristic. The curve for reverse voltage is shown in Fig. 11. Measured on continuous potential and at a voltage of 1500, the reverse current

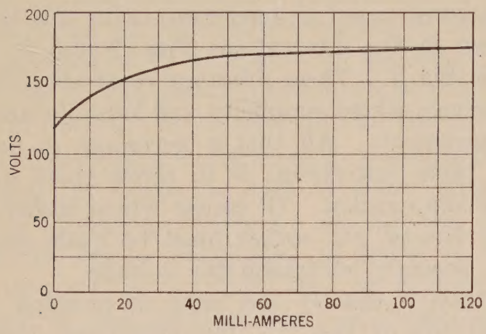

Fig. 10—Direct-Current Voltage Characteristic
Hollow electrode cathode

of the above tube is about 1.5 milliamperes. This completeness of rectification is also shown by the oscillogram of Fig. 12, which shows the current delivered to a resistance load with the tube operating on a 1000-volt a-c. circuit. Any of the usual rectifier circuits may, of course be used. Both halves of the a-c. wave may be rectified and the delivered d-c. potential smoothed out in the usual manner.

The tube noted above has a reasonable continuous overload capacity. Momentarily it can carry very much higher currents than normal. For a period of one second the tube may safely carry 10 amperes, or even more, and will rectify correctly under these conditions. Fig. 13 shows an oscillogram of current taken when the tube was thus handling a current of about this magnitude. Since the cooling of such a tube is largely by convection of the enclosed gas, the electrodes run normally much below a red heat, and the cooling is limited only by the facility with which the glass walls can dissipate to the surrounding air.

These tubes will operate in series and in parallel. In order to get very accurate sharing of current for parallel operation it is advisable to connect a small resistance in series with each tube. This is, however,

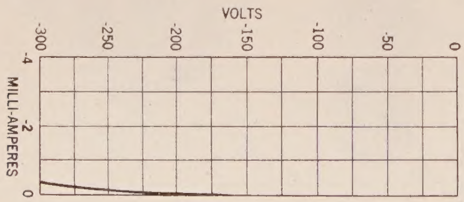

Fig. 11—Direct-Current Voltage Characteritics
Hollow electrode anode

not necessary if the tubes are correctly paired, for the characteristic is rising and parallel operation is accordingly stable. In series, no particular precautions are necessary. A high voltage will be equally shared between the tubes. It should be particularly noted in this connection that, when the tubes are used in series for the production of higher voltage, there is no problem of the insulation of filament batteries or other auxiliary devices. The tubes with their sockets as a whole are the only things that need to be insulated against full line potential.

When a tube of this model is operating, there is nothing that can be seen, except where a glow can be observed through a pinhole made in the cathode for this purpose. The heating of the bulb is the only indication that load is being carried.

The life of these tubes is very long. Tests made extending over several thousand hours on a number of models have not shown a change of 5 per cent in the characteristic at any time, and an examination of the

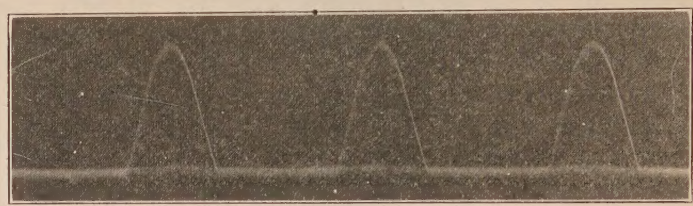

Fig. 12

electrodes at the end of such period has shown no measurable disintegration. It may be safely assumed for all ordinary purposes that the life is practically indefinite.

These tubes do not have the instantaneous current limitation of the thermionic rectifier. Also the characteristic does not pass through the origin, as is there the case. There are many uses in which such a current limit or characteristic is necessary. The internal drop in the present models is inherently higher than in other types of rectifiers now in use on low-voltage circuits. As is usually the case with electrical apparatus, the rectifier field will always be shared by a number of

Fig. 13

widely different devices each particularly adapted for the use to which it is put. The particular portion of the field which will be occupied by the tube here described may be fairly accurately predicted from an examination of its inherent properties as presented in the paper above.

VIII. Summary

Of the various types of non-metallic conduction, that employing electrons and gaseous ions is particularly noted. For practical purposes it has many advantages, such as the use of cold electrodes, comparatively unlimited current, and no inherent consump-

tion of the working parts. In the past, however, this gaseous conduction has been little utilized commercially for it has been erratic and unreliable, and disintegration of electrodes and loss of working gas have accompanied it, with resulting short life.

A new engineering principle, the short path law, and closely connected ideas, have resulted in practically removing these disabilities. The discharge can now be made to occur where it is wanted, and controlled; so that devices employing gaseous conduction may be made consistent in behavior and reproduceable. By limiting the discharge entirely to electrodes which are constructed of certain favorable materials, disintegration has been made to disappear, and with it all trace of gaseous clean-up. The result is the possibility of constructing gaseous conduction devices which can be depended upon and which will last indefinitely.

Many applications of the principles may be made. Two of these, both rectifiers, illustrate the possibilities of the new arrangement. The first, described only briefly, obtains its control by the use of a magnetic field. The second obtains a similar control by the use of a space charge. The control is so complete that a ratio of currents in two directions of several thousand to one can readily be obtained. These rectifiers will readily stand a back voltage of several thousand. The current which they can pass is limited only by the question of getting rid of the heat evolved. The internal drop is around two hundred volts with the usual arrangements of the device. Heavy currents can be passed for short intervals.

One commercial model of this form of *S*-tube is rated at 50 milliamperes continuously, and 1500 volts back voltage. It has a substantial continuous overload capacity. It is designed primarily for charging fire alarm batteries and for the use of radio amateurs. For convenience, it is built to be screwed into the ordinary standard lamp socket. No other appurtenances or auxiliaries are necessary. The life is very long. The efficiency depends upon the circuit, and is high when high voltages are rectified. Such tubes may be used in series or parallel to any desired extent in order to obtain a desired voltage, current, or output.

Ambient Temperature Measurements

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IN order to determine what difference exists between ambient and room temperatures, as defined by the A. I. E. E. Standards, a test was made in the electrical laboratories of the Johns Hopkins University. A generator was operated at constant load for a period of seven and one-half hours and the ambient and room temperatures were measured during the run, as described below.

Generator. The generator is a 100-kw., 250-volt, three-wire, direct-current generator and is driven by a steam turbine. The speed is 2400 rev. per min. The generator was operated at a constant load of 350 amperes and 240 volts during the test. This is approximately 90 per cent of full-load rating.

The room in which the unit tested is located is 65 ft. long. by 46½ ft. wide. The center line of the generator is 27 ft. from the east wall of the room and 14 ft. from the south wall.

Temperatures. The generator temperature was measured by three thermometers, located as follows: One on the interpole windings, one on the shunt field windings, and one on the series field windings. The generator temperature as reported below is the average of the three thermometer readings.

The ambient temperature was measured by five thermometers placed at the level of the central plane of the machine and around it at an average distance of 4.3 ft. from the machine. These thermometers were placed in oil cups in accordance with the A. I. E. E. Standards. The ambient temperature as reported below is the average of the five thermometer readings.

The room temperature was measured by four thermometers placed on the four walls of the room. The room temperature as reported below is the average of the four thermometer readings.

All temperatures given below are in degrees centigrade. They were measured by thermometers that had been carefully checked.

RESULTS

Time	Average Temperatures			Difference between room and ambient Temperatures
	Ambient	Room	Generator	
9.00	27.20	26.65		+ 0.55
10.00	27.80	27.50	48.3	+ 0.30
11.00	28.50	28.61	51.5	− 0.11
12.00	29.46	29.38	53.7	+ 0.08
1.00	30.86	30.55	55.0	+ 0.31
1.30	31.32	30.85	55.5	+ 0.47
2.00	31.58	30.98	55.87	+ 0.60
2.30	31.64	30.78	55.87	+ 0.66
3.00	31.90	31.20	55.90	+ 0.70
3.30	32.00	31.23	56.00	+ 0.77
4.00	32.14	31.13	55.92	+ 1.01
4.30	32.20	31.15	56.00	+ 1.05

Conclusion. The test shows a maximum difference between the ambient temperatures, as determined in accordance with the Standards of the A. I. E. E., and the room temperature of 1.05 degrees centigrade.

Probable Values of Conventional Allowance for A-C. Generator Stator Windings

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THE principle employed in the A.I. E. E. Standards for determining the limiting temperature rises as a basis for rating is the so-called hottest-spot principle. The hottest-spot temperature is the bench mark or original point of reference and the limiting observable temperature is derived from it by subtracting a temperature that represents the difference between this temperature and the highest temperature that it is possible to measure by commercial methods. This difference is known in the A. I. E. E. Standards, as the "conventional allowance."

This basis for determining limiting observable temperatures can scarcely be criticized on theoretical grounds. It has been criticised, however, and with reason, because of the practical difficulties attending the evaluation of the conventional allowance. These practical difficulties have been greatly increased by the conception of the conventional allowance as an attribute of the method of measurement alone, resulting in a single conventional allowance for each recognized method of measurement.

Experience in building up standards under this principle has shown that it is impossible for a single value to satisfy all the practical situations arising. The conventional allowance with a certain method of measurement will vary with the total temperature or temperature rise; this has led to the suggestion that different values of conventional allowance be assigned for the different temperature limits of the different classes of insulation. But, even with a given method of measurement and a given limiting temperature the proper conventional allowance may still vary considerably because of the widely different conditions existing in different applications. For example, a conventional allowance for the thermometer method of measurement (with Class A Insulation temperature limits) may vary considerably in these several applications: A small induction motor stator winding, a large wire-wound shunt field coil, or an air-blast transformer winding. Or, to consider another class, the conventional allowance for the resistance method of measurement (with Class B insulation temperature limits) may vary considerably in a turbine type generator rotor winding and in a relatively small railway motor armature winding.

A consideration of these facts has led many engineers away from the idea of a single value of the conventional allowance applicable to a given method of measurement toward the idea of a conventional allowance associated with a single particular application. The former conception made the values of conventional allowance general in their application and the numerical values naturally became a part of the principle. The latter conception makes the values limited and specific in their use and divorces them from the general principle; this strengthens both the principle and the application of the principle to practical cases.

The work described in this paper has been based on this second conception of the conventional allowance. It has been attempted to determine experimentally the value of the conventional allowance for this particular method of measurement when applied to a given class of alternating-current machine stator windings for given temperature limits.

This experimental work has been of two kinds: First, the measurement in machines of various sizes and voltages of copper temperatures by detectors inside the coil insulation) and of "observable" temperatures (by detectors located between the two coil sides in a slot) thus determining, by direct measurement, the data on which values of conventional allowance can be based; and second, an investigation of the influence of various factors such as insulation thickness, eddy current losses, core length and core temperature on the conventional allowance, by using a small armature model in which these several factors can be varied conveniently.

The tests on generators have been carried out under the direction of the Subcommittee on Rotating Machinery of the Standards Committee and the author acknowledges, with pleasure, his indebtedness to the Committee for permission to publish this information. Mr. C. J. Fechheimer is responsible for the interpretation of the model test results and the development, therefrom, of the formulas for the calculation of values of conventional allowance and top-coil copper temperatures.

Model Tests

In Figs. 1 and 2 are shown the details of a model designed to reproduce the temperature conditions in a radially ventilated armature core.

Thermocouples are distributed throughout the coils and core as indicated, so as to measure the true copper temperature, the temperature between coils and the average tooth temperature.

The several factors whose influence on the conventional allowance it is desired to study were reproduced as follows:

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1. In order to imitate the conditions that obtain in a long machine, the coil ends were blocked so that the cooling of the ends by forced convection was very

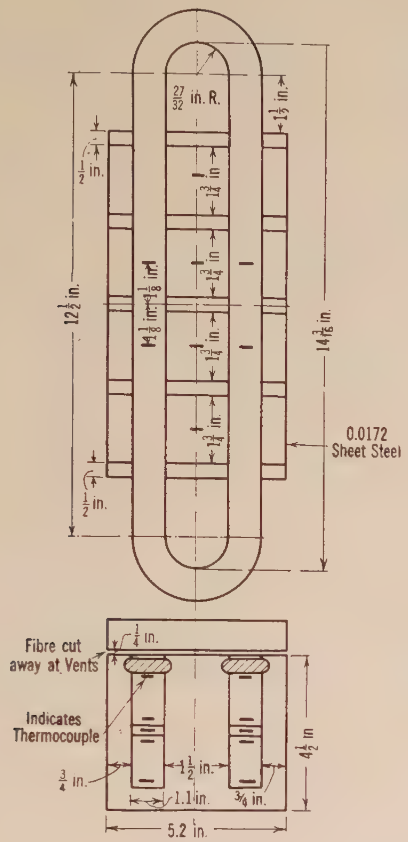


FIG. 1

Two coils, each consisting of eighty turns of 0.095-in. by 0.122-in. d. c. c. arranged 8 by 0.095 in. wide.

small. Thermocouples in the ends then showed nearly the same temperature as the copper in the embedded part, and therefore the longitudinal heat flow was negligible, thus simulating conditions that obtain at

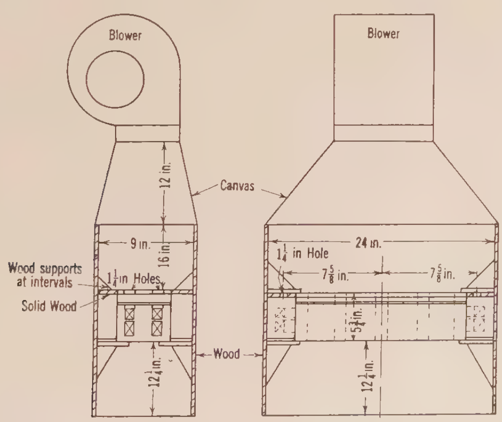


FIG. 2

the middle of a long-core machine. The short-core machine was imitated by opening the coil ends to the ventilating air streams.

2. The temperature of the iron was altered by changing the speed of the blower supplying the cooling air. By this means the iron temperature rise was changed from 10.5 to 70 deg. rise for the long-core, or from 9 to 40 deg. rise for the short-core machine, with the same current in the coils.

3. In all tests, direct current was used in the two coils. In order to imitate the influence of eddy currents the value of current in the upper coil was changed, the current in the lower coil being kept substantially constant throughout the tests.

4. The coil insulation was nominally for 6600 volt wrapper but it was crowded into a smaller space than is ordinarily used for that voltage. The wall thickness was approximately 0.11 in. Extra insulation was placed between coils, as shown in Fig. 3. The extra insulation was about 0.32 in. thick, thus making the

equivalent wall thickness $\frac{0.32}{2} + 0.11 = 0.27$ in, or

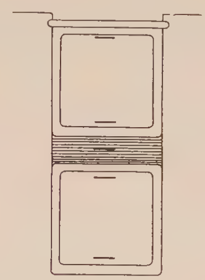


FIG. 3

slightly greater than would be used for 13,200 volts. Tests were made with and without this extra insulation.

Twenty eight different temperature tests were made under various conditions; the first series was equivalent to a 13,200-volt long-core generator with varying eddy current losses (varying loss ratio) and with varying core temperatures; similar series of tests were made for a 6600-volt long-core armature and for 13,200-volt short-core armatures. All temperature tests were continued until steady temperatures were attained. The test results of all runs are summarized in Table I and the results of typical runs are plotted in the accompanying curves.

Fig. 4 shows the variation in temperature rises for different blower speeds, equivalent to different core temperatures, with 20 amperes in each coil and imitating the long-core machine. (The reciprocals of blower speeds are used as abscissas in order that the curves approach straight lines). It will be seen that the maximum copper temperature and iron temperature curves are nearly parallel, indicating that although the iron temperature rise increased from 10.5 deg. to 70 deg. the drop from the copper to the iron changed but little; and this small increase was largely due to the increase in copper temperature with resistance. This relation is to be expected from the fundamentals

TABLE I

SUMMARY OF TESTS ON ARMATURE MODEL

Long or short core	Extra ins. bet coils	Fan rev. per min.	Amps. top coil	Amps. bot. coil	Loss Ratio = (Itop/Ibot.)	Temp. R Pos 1	Temp. R Pos. 4 θm	Temp. R Iron θi	Temp. R Air	Mean of temp. Pos (2) & (3)	Mean of 2 and 3 H −4 = θa	Test top coil temp. rise Pos. 2	Test bot coil temp. r. Pos. 3
Long	Yes	150	20	20	1.	110	97	70	20	115.5	18.5	115	116
"	"	200	"	"	"	89	78	53	12	96	18.0	96	96
"	"	300	"	"	"	73	60	37	9	78	18.0	78	78
"	"	600	"	"	"	57	43	22	6	61	18.0	61	61
"	"	900	"	"	"	49.5	34.5	16.5	4.5	53.5	19.0	53.5	53.5
"	"	1400	"	"	"	40.5	24.5	10.5	2.0	43.5	19.0	43.5	43.5
"	"	300	25	20	1.56	121.5	89.5	52.5	12.5	112.5	23	128.5	96.5
"	"	1400	20	"	1.0	43	27	11.0	2.2	46	19	45	47
"	"	"	25	"	1.56	69	38	17	3.2	60	22	71	49
"	"	"	28	"	1.96	89	47	20	4.0	71.5	24.5	90	53
"	No.	1400	20	20	1.00	42	40	11	4.0	48	8.0	47	49
"	"	"	25	"	1.56	66.5	55.5	14.5	6.3	63	7.5	71.5	54.5
"	"	"	27.5	"	1.89	84.0	69.0	19	8.0	76	7.0	91.0	61.0
"	"	600	20	20	1.00	61.0	63	28	12.25	69.75	6.75	68	71.5
"	"	"	25	"	1.56	88.5	83.5	30.5	13.5	88.0	5.50	97.5	78.5
"	"	"	27.5	"	1.89	114.5	104.5	40.5	19.0	108.5	4.00	125.5	91.5
"	"	300	20	20	1.00	82.5	86.5	45.5	22.0	92.0	5.5	91.5	92.5
"	"	"	24.7	19.4	1.62	124.5	118.5	60.5	32.5	121.5	3.0	133.5	109.5
"	"	"	27.5	19.6	1.97	149.5	139.5	70.5	35.5	144.5	5.0	164.5	124.5
Short	Yes	150	20	20	1.00	66	59	40	11	71.5	12.5	70	73
"	"	230	"	"	"	55	47	30	8.5	60.0	13.0	58	62
"	"	310	"	"	"	48	41	24	6.8	52.5	11.5	51	54
"	"	400	"	"	"	44	36	20	5.0	47.5	11.5	46	49
"	"	600	"	"	"	39	31	15	3.2	42.5	11.5	41	44
"	"	1400	"	"	"	33	22	9	2.0	36	14.0	35	37
"	"	"	25	"	1.56	50	31	13	2.5	46.5	15.5	55	38
"	"	"	24.5	20.8	1.50	49.5	31.5	11.5	2.5	46.0	14.5	53.5	38.5
"	"	"	27.5	20.0	1.90	60.0	36.0	13	2.8	52.0	16	65.0	39

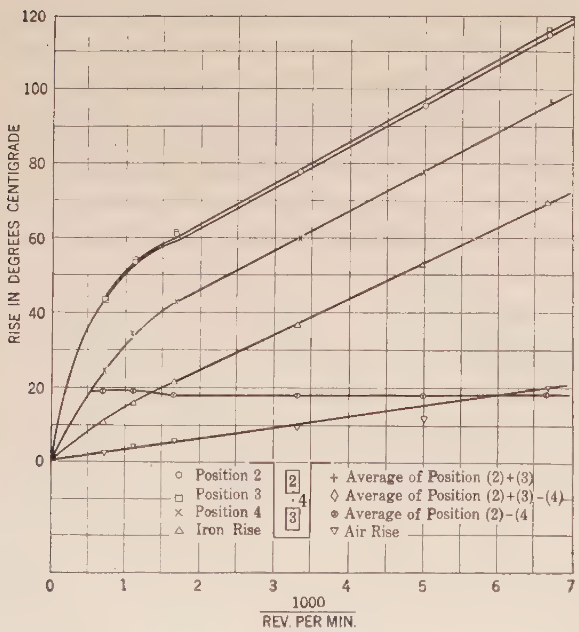


Fig. 4—Temperature Rise as a Function of Reciprocal of Fan Rev. Per Min.

Twenty amperes d-c in both coils. Ends poorly ventilated. Long core machine. ¼ in. extra insulation between coils.

of heat flow and temperature drop. This is the first important fact to be observed.

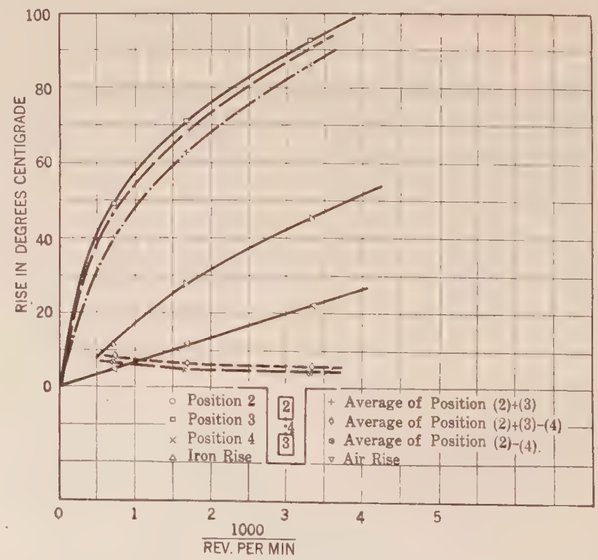


Fig. 5—Temperature Rise as a Function of Reciprocal of Fan Rev. Per Min.

Twenty amperes d-c. in both coils. Ends poorly ventilated. Long core machine. No extra insulation between coils.

The second important fact may be noted from Figs. 4, 5, and 6 viz., the amount or velocity of cooling air

has no effect upon the total temperature drop through the insulation, or on the difference between copper and observable temperatures, (if allowance is made for the increase in resistance with temperature). It follows,

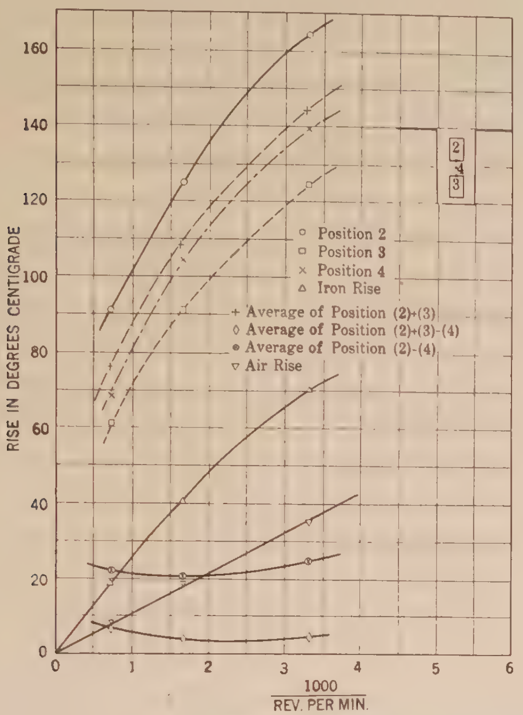


FIG. 6—TEMPERATURE RISE AS A FUNCTION OF RECIPROCAL OF FAN REV. PER MIN.

Twenty amperes d-c. in lower coil. 27.5 amperes d-c. in upper coil. Ends poorly ventilated. Long core machine. No extra insulation between coils.

that charges in armature temperatures caused by changes in ventilation are not accompanied by any changes in conventional allowances.

The third important fact is that there is substantially a constant difference between the mean of the top and bottom coil temperatures and the observable temperature rise (detector between coils,) provided the loss in the bottom coil is not altered and the insulation thickness is fixed. This may be seen to hold with reasonable accuracy whether or not the ventilation (or iron temperature) change through wide limits; whether or not the eddy current loss be materially changed; Figs. 7 and 8; whether the wall of insulation be thin or thick (provided it is not changed during a series of tests); or if the core be long or short. This fact is interesting and of value, and to our knowledge has not been pointed out by any one previous to this investigation. This temperature difference, it should be noted, exists in spite of equal temperatures in top and bottom coils. We have been accustomed to think that under this condition of equal coil temperature, the observable temperature is equal to the copper temperature. Such, however, is not the case because there is heat flow to the slot sides from the adjacent sides of the coils and from this series of tests a measure of the temperature drop caused by this flow was obtained. Thus, (see Table I) this drop for the same current in both coils, was 18 to 19 deg. for iron temperature rises of 10.5 deg. to 70 deg., (with extra insulation between coils); and was 10.5 deg. to 13 deg. for variations in iron temperature rises from 9 deg. to 40 deg. (for no extra insulation between coils). With variations in loss ratio, for a given insulation and core length, the change in this drop is slightly greater, but still can be considered as constant with reasonable accuracy.

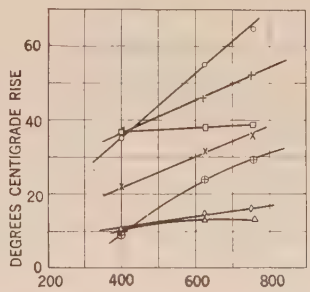
These relations are used in deriving the equations for calculating the conventional allowance. Let

θ_t = the temperature rise of the copper in the top coil

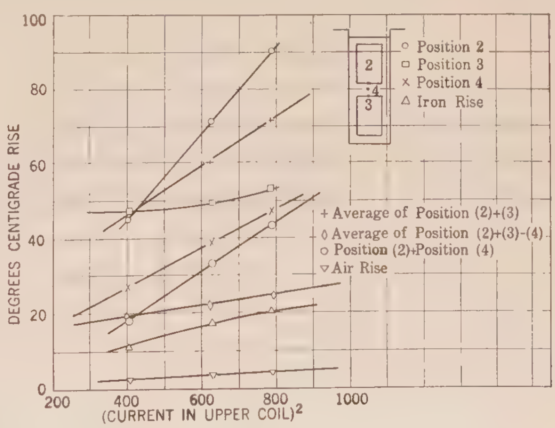
θ_b = the temperature rise of the copper in the bottom coil

θ_m = the temperature rise by detector between coil sides

θ_a = the temperature difference between the means of top and bottom coil temperatures and the temperature by detector between coils. This is equivalent to the drop in temperature due to heat flow to the slot sides and is constant under certain conditions.



Tests at 1400 rev. per min. of fan. Twenty amperes d-c. in lower coil in all tests. Temperature rises as a function of square of current in upper coil. ¼ in. extra insulation between coils.



Ends poorly ventilated. Long core machine.

FIG. 7

By definition

$$\theta_a = \frac{\theta_t + \theta_b}{2} - \theta_m \qquad (1)$$

It is reasonable to assume that the temperature rises of the top and bottom coils above the temperature of

the adjacent core teeth is proportional to the losses in these coils; the ratios of these temperature rises will be equal to the ratio of the losses. The loss in each

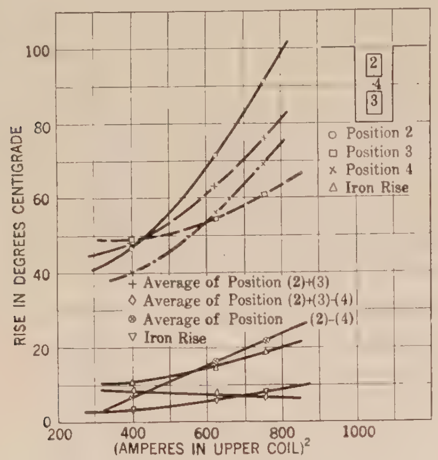


FIG. 8—TEMPERATURE RISE AS A FUNCTION OF SQUARE OF CURRENT IN UPPER COIL

Current in lower coil constant equals twenty amperes. Fan speed constant equals 1400 rev. per min. Ends poorly ventilated. Long core machine. No extra insulation between coils.

ratio of coil losses be designated by $L.\,R.$ and the core tooth temperature by θ_i; then:

$$L.\,R. = \frac{\theta_t - \theta_i}{\theta_b - \theta_i} \tag{2}$$

In the usual case, θ_i and θ_m are measured, and the constant θ_a, is determined by test on similar apparatus. The loss ratio may be estimated from eddy-current calculations. We then have two equations, and two unknowns, θ_b and θ_t. Solving for them,

$$\theta_b = \frac{2\,(\theta_m + \theta_a) + \theta_i\,(L.\,R. - 1)}{L.\,R. + 1} \tag{3}$$

$$\theta_t = \frac{2\,L.\,R.\,(\theta_m + \theta_a) - \theta_i\,(L.\,R. - 1)}{L.\,R. + 1} \tag{4}$$

Also from (1)

$$(\theta_b + \theta_t) = 2\,(\theta_m + \theta_a) \tag{5}$$

The conventional allowance is

$$\theta_c = \theta_t - \theta_m = \frac{(\theta_m - \theta_i)\,(L.\,R. - 1) + 2\,\theta_a\,L.\,R.}{L.\,R. + 1} \tag{6}$$

The difference between the upper and lower coil temperatures is

TABLE II

COMPARISON OF CALCULATED AND TEST RESULTS—ARMATURE MODEL

Long or short core	Extra Ins. bet. coils	Fan rev. per min.	Amps. top coil	Amps. bot. coil	Value $\theta\,a$ used in formula	Value of $\theta\,i$ in formula	Value of $L\,R$ in formula	Calc. top coil temp. rise	Test top coil temp. rise for pos. 2	Calc. bot. coil temp. rise pos. 3	Test bot. coil temp. rise pos. 3	Calc. conv. allowance $\theta\,c\,a$	Test $\theta\,c\,a$ pos. (2) pos. (4)	Diff. bet. test and calc. pos. 2	same as % of pos. (2) temp. rise
Long	Yes	150	20	20	20	70	1.0	117	115	117	116	20	18	− 2	1.7
"	"	200	"	"	20	53	"	98	96	98	96	20	18	− 2	2.1
"	"	300	"	"	20	37	"	80	78	80	78	20	18	− 2	2.6
"	"	600	"	"	20	22	"	63	61	63	61	20	18	− 2	3.3
"	"	900	"	"	20	16.5	"	54.5	53.5	54.5	53.5	20	19	− 1	1.9
"	"	1400	"	"	20	10.5	"	44.5	43.5	44.5	43.5	20	19	− 1	2.3
"	"	300	25	20	20	52.5	1.56	122	128.5	97	96.5	32.5	39	+ 6.5	− 5.1
"	"	1400	20	20	20	11.0	1.0	47	45	47	47	20	18	− 2	4.4
"	"	"	25	20	20	17.0	1.56	67	71	49	49	29	33	+ 4	− 5.6
"	"	"	28	20	20	20.0	1.96	82.5	90	52	53	35.5	43	+ 7.5	− 8.3
"	No	1400	20	20	6	11.0	1.00	46	47	46	49	6	7	+ 1	− 2.12
"	"	"	25	20	6	14.5	1.56	72	71.5	51.2	54.5	16.5	16.0	− 5	.7
"	"	"	27.5	20	6	19	1.89	92.4	91.0	57.8	61	23.4	22	− 1.4	1.5
"	"	300	20	20	6	45.5	1.00	92.5	91.5	92.5	92.5	6	5	− 1.0	1.1
"	"	"	24.7	19.4	6	60.5	1.62	140	133.5	109	109.5	21.5	15	− 6.5	4.9
"	"	"	27.5	19.6	6	70.5	1.97	170	164.5	12.1	124.5	30.5	25	− 5.5	3.3
"	"	600	20	20	6	28.	1.00	69.	68.	69.	71.5	6.	5	− 1.0	1.4
"	"	"	25	"	6	30.5	1.56	102.5	97.5	76.8	78.5	19.	14	− 5.0	5.1
"	"	"	27.5	"	6	40.5	1.89	132.	125.5	89.2	91.5	27.5	21	− 6.5	5.2
Short	Yes	150	20	20	13	40	1.00	72	70	72	73	13	11	− 2	2.9
"	"	230	"	"	13	30	1.00	60	58	60	62	13	11	− 2	3.5
"	"	310	"	"	13	24	1.00	54	51	54	54	13	10	− 1	2.0
"	"	400	"	"	13	20	1.00	49	46	49	49	13	10	− 1	2.2
"	"	600	"	"	13	15	1.00	44	41	44	44	13	10	− 1	2.4
"	"	1400	"	"	13	9	1.00	35.0	35	35.0	37	13	13.0	0.0	00.0
"	"	"	25	"	13	13	1.56	50.7	55	37.3	38	19.7	24	+ 4.3	− 7.8
"	"	"	24.5	20.8	13	11.5	1.50	51.2	53.5	37.9	38.5	19.7	22	+ 2.3	− 4.3
"	"	"	27.5	20.0	13	13.0	1.90	60.0	65.0	38.0	39.0	24	29	+ 5	− 7.7

coil is the $I^2\,R$ loss plus the eddy current loss, both of which can be calculated in a given case.[1] Let this

1. See Eddy Current Losses in Armature Conductors. R. E. Gilman, A. I. E. E. TRANSACTIONS 1920; also article by S. L. Henderson, *Electric Journal*, September 1920, giving principal formulas with examples.

$$(\theta_t - \theta_b) = \frac{2\,(\theta_m + \theta_a - \theta_i)\,(L.\,R. - 1)}{L.\,R. + 1} \tag{7}$$

Equation (4) then gives the top coil temperature rise, and equation (6) gives the conventional allowance.

It remains to establish the variation of θ_a with core length, insulation thickness and rate of heat flow. This can be done from the results of the model tests and the

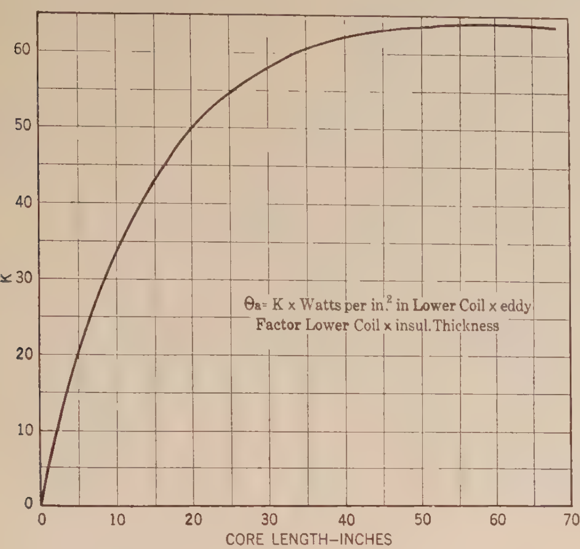


Fig. 9

generator tests described later. It will be noted that the following values were obtained for the conditions tested and were used in obtaining the calculated values given in Table II.

For 13,200-volt insulation and very long core (say in excess of 60 inches).......20 deg.

For 13,200-volt insulation and very short cores (8 1/2 inches)..................13 deg

For 6600-volt insulation and very long core.... 6 deg.

The value θ_a remains constant with varying loss ratios, varying core temperatures and with constant loss in the bottom coil as shown by the model tests.

No tests were made with varying loss in the bottom coil but a little consideration will show that the heat flow to the slot sides (and consequently the value of θ_a) will vary in proportion to the rate of heat flow from the bottom coil (or the watts per square inch of coil surface).

It is also assumed (from the fundamentals of heat flow) that θ_a is proportional to the insulation thickness. We may then write

$$\theta_a = K \times \text{watts per sq. in.} \times \text{insulation thickness} \quad (8)$$

In this expression K varies with core length. In long core machines (say over 60 inches) the heat generated in the copper at the center of the core is transmitted wholly across the insulation wall to the core. As the core length diminishes a greater part of the heat generated in the copper at the center of the core is transmitted along the copper to the external coil ends and the part transmitted across the insulation wall diminishes. The effect of variation in core length, therefore, is to vary the watts per square inch transmitted across the insulation wall. The relations between core length and division of heat flow between

TABLE III

Machine Number	Rating					Core Length	Insulation thickness	Test Conditions			Data under Test Conditions						Maximum Temperature Rise					Conv. Allowance
	K. V. A.	Frequency	Volts	Amp	R. P. M.			Volts	Amp.	Power factor	Amp. per sq. in. in Conductor	Watts per sq. in. at 75° C. Top Coil	Watts per sq. in. at 75° C. Bot. Coil	Eddy current factor (Top)	Eddy current factor (Bottom)	Loss Ratio	(1) Top of upper coil	(2) Bot. of upper coil	(3) Top of bot. coil	Between coils (4)	Between top coil and tooth (5)	
1	1250	60	2300	313	300	14	0.125	2300	313	0	3410	1.02	1.00	1.02	1.004	1.016	46.6	52.7		51.4	44.5	1.3
2	1250	60	2400	300	3600	33.5	0.138	2400	300	0	2170	0.584	0.564	1.106	1.07	1.03		53.0	48.5	48.2	37.0	4.8
								2400	383	0	2770	0.950	0.920	1.106	1.07	1.04		73.5	67	68.0	44.0	5.5
3	1560	60	2200	410	3600	46	0.162	2000	451	0	1820	0.455	0.391	1.215	1.04	1.16	68.3	58.9		46.2	32.5	12.7*
4	3000	25	2300	750	750	33	0.125	2300	545	0	1860	0.400	0.392	1.02	1.004	1.015	30	32.3		32.3	25.4	0.0
								1835	753	0	2580	0.764	0.750	1.02	1.004	1.015	41.5	45.5		45.5	32.5	0.0
5	3125	62	2300	785	750	25	0.115	2300	559	0	1890	0.504	0.449	1.215	1.084	1.12	45	48.5		48.5	41.0	0.0
								1940	785	0	2660	0.991	0.886	1.215	1.084	1.12	59.5	65.0		64.0		1.0
6	750	60	6600	65.6	300	14.5	0.131	6600	58.3	0	2200	0.577	0.562	1.03	1.004	1.025	35	36		34		2.0
7	1250	25	6400	113	306	13	0.182	6400	113	0	2460	0.766	0.760	1.008	1.000	1.008	55.8	61.3		59.4	40.8	1.9
8	2450	25	6600	214	750	25	0.175	6600	180	0	2090	0.533	0.527	1.026	1.014	1.009	33	35		29	25	6.0
9	2500	60	6600	219	240	13	0.117	6600	219	0	2670	1.71	1.25	1.45	1.06	1.37	78.5	75	74	72	62.5	3.0
10	5500	60	6600	481	225	22.5	0.144	6600	481	0	1970	0.790	0.63	1.34	1.07	1.25	77.5	68.5	65	63.5	60.5	5.0
11	6000	60	6600	525	600	21.5	0.142	6600	525	0	2510	1.278	1.01	1.35	1.07	1.26	83.8	82.5	79.5	72.1	61.9	10.4
12	12000	60	6600	1050	150	33	0.165	6600	960	0	1820	0.821	0.645	1.58	1.24	1.27	78.3	72.6		64	54	8.6
13	2500	50	11000	131	750	15	0.24	0	131	s. c.	2245	0.62	0.595	1.061	1.02	1.04	38.4			29.8	28.0	8.6
								11000	131	under exc. 0	2300	0.814	0.756	1.186	1.026	1.15	68	76		66		10.0
14	2500	50	11000	131	750	16	0.211															
								11000	131	over exc. 0	2300	0.874	0.756	1.186	1.026	1.15		95		88		7.0
15	1250	50	15000	48	750	20		15000	48	.90							32	33	52	28	26.5	5.0
								15000	72	.95							51.5	52.5		41.5	37.0	11.0
16	3500	50	10000	202	750	27		10000	250	0							56.5	61†	60	48.5	43	12.5

In machines 1-4-5-7-8-13-15-16—10-inch resistance detectors are used; those inside main insulation are in contact with cotton covering of wires; other machines have thermocouples and couples inside insulation are in contact with bare copper. All detectors are located in center of core, lengthwise.

*Temp. affected by flux from field augmenting loss in upper coil.

†Bottom of bottom coil.

the transverse and longitudinal paths are quite complicated, but these have been investigated and the general shape of the curve is known.[2]

The curve, Fig. 9, showing the relation between K and core length has been arrived at from a consideration of these general relations, and the experimental data from both the model tests and the tests on machines. The data from the model tests with extra insulation between coils have not been used (except as an indication of the relative variation of K with core length) because of the known fact that the heat conductivity of laminated insulation varies greatly with and across the laminations.[3] With the extra insulation between coils as used in the model, the layers of the insulation were not rounded, as would be the case with coil insulation, but lay flat. See Fig. 3. Consequently the side flow of heat was greater and the temperature drop was greater than in the usual case.

of the A. I. E. E. arranged to make tests on generators of three different manufacturers to obtain data that would be useful in the revision of the temperature limits of large machines using the embedded temperature detector method of measurement.

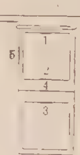
Tests were made on sixteen generators ranging in size from 750 kv-a. to 12,000 kv-a. at various voltages from 2300 volts to 15,000 volts and speeds from 150 rev. per min. to 3600 rev. per min. Very large turbine type generators were not included in this program, because another series of tests on such machines had previously been arranged.

The tests conducted by the subcommittee were made in the testing departments of the several manufacturing companies. Each test was supervised by the member of the subcommittee located at the plant. In all of the machines detectors were built into the armature coils to measure the temperature of the copper of the

TABLE IV

Machine No.	Core length	Value of K	Insulation thickness	Watts per sq. in bottom	Calc. value θ_a	Loss ratio	θ_m	θ_i	Calc. value θ_r	Tested value θ_r	Calc. value conventional all.	Tested value conventional all.	[θ (test) $- \theta_t$ (calc.)] $\times$ 100 / θ_r (test)	
1	14	42	0.125	1.00	5.25	1.016	51.4	44.5	56.8	52.7	5.4	1.3	− 7.8	
2	33.5	60	0.138	0.564	4.65	1.03	48.2	37	53.2	53	5.0	4.8	− .38	
				0.920	7.65	1.03	68.0	44	76.3	73.5	8.3	5.5	− 3.8	
3	46	63	0.162	0.391	4.00	1.16	46.2	32.5	51.6	58.9	5.4	12.7*	+ 14.2	
4	33	59.5	0.125	0.392	2.90	1.015	32.3	25.4	35.3	32.3	3.0	0.0	− 9.3	
				0.750	5.50	1.015	45.5	32.5	51.3	45.5	5.8	0.0	− 12.7	
5	25	54.5	0.115	0.449	2.82	1.12	48.5	41.0	51.9	48.5	3.4	0.0	− 7.0	
				0.886	5.60	1.12	64.0	54†	70.5	65.0	6.5	1.0	− 8.5	
6	14.5	43	0.131	0.562	3.18	1.025	34	33†	37.9	36.0	3.9	2.0	− 4.5	
7	13	39	0.182	0.760	5.40	1.008	59.4	40.8	64.8	61.3	5.4	1.9	− 5.4	
8	25	54	0.175	0.527	5.0	1.009	29	25	34	35	5	6	+ 2.85	
9	13	39	0.117	1.25	5.72	1.37	72	62.5	80	75	8.0	3.0	− 6.25	
10	22.5	52	0.144	0.63	4.7	1.25	63.5	60.5	69.1	68.5	5.6	5.0	− 8.7	
11	21.5	50	0.142	0.63	7.2	1.26	72.1	61.9	81.4	82.5	9.3	10.4	+ 1.09	
12	33	60	0.165	0.645	6.5	1.27	64.0	54.0	72.5	72.6	8.5	8.6	+ 1.3	
13	15	43	0.24	0.595	6.25	1.04	29.8	28	36.3	38.4‡	6.5	8.6	+ 6.0	
14	16	44	0.211	0.756	7.0	1.15	66	58†	74.4	76	8.4	10	+ 2.1	under exc.
				0.756	7.0	1.15	88	70†	96.8	95	8.8	7	+ 1.87	over exc.

*Temperature affected by flux from field augmenting loss. Iron temperature at bottom of slot.
†Iron temperature assumed, not given from test.
‡On copper of top of upper coil.
Note: Iron temp. not given from tests: The iron temperature rises by thermometer were increased by amounts indicated by tests on other machines. The iron temperature, as used in formula, has small influence upon the copper temperature, except when the loss ratio is high.



In equation (8) the watts per square inch refer to the bottom coil, the watts being the $I^2 R$ loss at 75 deg. cent., plus the calculated eddy current loss in the bottom coil at the same temperature, and the surface being that of the bare copper, omitting the side adjacent to the top coil. The insulation thickness is taken as one-half the difference between slot width and bare copper width.

Generator Tests

At a meeting held November 4, 1920, the Rotating Machinery Subcommittee of the Standard Committee

top coil and detectors were located between coil sides. In some of the machines detectors were also located inside the insulation of the bottom coil and between the top coil and core tooth.

The essential design information and test results are given in Table III.

A word of caution may be required against using these generator tests *directly* for estimating probable or reasonable limiting values of conventional allowance or measureable temperature rise. The generators selected for test were, in six cases, of shorter core length than the limit set in the Rules for the detector method of measurement; in five cases were for low voltage; in three cases were for low frequency; and in general were of such size and characteristics that low rises and values of conventional allowance should be expected.

2. Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils. C. J. Fechheimer, JOURNAL, A. I. E. E., March, April and May 1921.

3. The Thermal Conductivity of Insulating and other Materials, T. S. Taylor, *Electric Journal*, December, 1919.

The entire class of large turbo generators was intentionally excluded. But while these tests may not be used directly for determining probable limiting values, they are as good as any for the purpose employed in this paper; viz., for checking the validity of the method of calculation that is developed from the model tests.

The formulas derived from the results of the model tests have been verified by checking values of the top coil temperature and conventional allowance calculated by them against the measured values of the machines tested. The results of this comparison are shown in Table IV. This agreement is sufficiently close to warrant the statement that the conventional allowance can be calculated with a fair degree of accuracy for any machine when the following data are available:

1. Observed temperature rise by detector between coil sides.
2. Observed temperature rise of tooth by detector at side or bottom of slot.
3. Ratio of copper loss to coil surface. (Watts per square inch.)
4. Eddy current losses (loss ratio).
5. Thickness of insulation.
6. Length of core.

As might be expected, some of the test results do not check with the calculated results as closely as others.

The two units No. 4 and No. 5 show practically no difference between the copper temperature and observable temperature. These two machines are among those having ten-inch detectors inside the main coil insulation (in contact with the cotton covering on the wires) instead of thermocouples in contact with the bare copper. With thin insulation (for 2300 volts) low loss ratios and low temperature rise, the conventional allowance will be naturally low and the method of measuring the copper temperature will have a relatively large influence on the measured difference between the copper and observable temperatures.

Unit No. 3 shows a higher measured conventional allowance than can be accounted for. This is a two-pole turbo-generator and the designer explains this discrepancy by the existence of extra losses in the top coil caused by the penetration of main rotor flux into the slot.

As will be evident by considering the method of derivation, the formula for calculating the top coil temperature gives the temperature of that part of the top coil adjacent to the bottom coil. (Position 2, Table III). In generators having small eddy current losses, this is the maximum temperature of the top coil; in generators having larger eddy current losses or in which the main field flux penetrates the slots, thus producing additional eddy current losses, the temperature of that part of the top coil adjacent to the air gap (Position 1, Table III) is the maximum. This is illustrated by the following figures taken from Table III.

Unit No.	L. R.	Position 1 top of upper coil	Position 2 bottom of upper coil	Diff.
3	1.16	68.3	58.9	9.4
9	1.37	78.5	75	3.5
10	1.25	77.5	68.5	9.0
11	1.26	83.8	82.5	1.3
12	1.27	78.3	72.6	5.7

In the comparison between measured and calculated top coil temperatures, the test values given in Table IV are for Position 2 in every case, and this fact should be considered in drawing any conclusions as to the probable range of values of conventional allowance in practise.

Calculation of the Conventional Allowance for Limiting Cases

The only values of the conventional allowance that are of interest from the standpoint of standardization are those that exist at the limiting copper temperatures. In determining the proper value of the conventional allowance for the temperature limit of Class *A* insulation, for example, the values of the conventional allowance that exist when the copper temperature is 105 deg. are the only ones that are of interest. It is possible, then, to assume various sets of conditions (all of which result in 105 deg. copper temperature) and to calculate the conventional allowance, and, in that way, obtain a quantitative idea of the range of values of the conventional allowance at the assumed limiting copper temperature.

TABLE V

CALCULATED CONVENTIONAL ALLOWANCES

6600-Volt Insulation—105 deg. Copper Temperature.
Insulation Thickness—0.15 inch
Calculations are based on long core machines.

Top coil temp. rise	65	65	65	65	65	65	65	65	65
Core temp. rise	25	35	45	25	35	45	25	35	45
Temp. drop through ins.	40	30	20	40	30	20	40	30	20
Watts per sq. in., top	0.8	0.6	0.4	0.8	0.6	0.4	0.8	0.6	0.4
Loss ratio	1.10	1.10	1.10	1.20	1.20	1.20	1.40	1.40	1.40
Watts per sq. in., bot.	0.73	0.54	0.36	0.67	0.50	0.33	0.57	0.43	0.28
θ_a	7	5.2	3.5	6.5	4.8	3.2	5.5	4.1	2.7
θ_m	56.2	58.4	60.6	55.1	57.7	60.1	53.8	56.6	59.4
Conventional allowance	8.8	6.6	4.4	9.9	7.3	4.9	11.2	8.4	5.6

TABLE VI

CALCULATED CONVENTIONAL ALLOWANCES.

13200-Volt Insulation—105 deg. Copper Temperature.
Insulation Thickness—0.25 inch
Calculations are based on long core machines.

Top coil temp. rise	65	65	65	65	65	65	65	65	65
Core temp. rise	25	35	45	25	35	45	25	35	45
Temp. drop through ins.	40	30	20	40	30	20	40	30	20
Watts per sq. in., top	0.48	0.36	0.24	0.48	0.36	0.24	0.48	0.36	0.24
Loss ratio	1.10	1.10	1.10	1.20	1.20	1.20	1.40	1.40	1.40
Watts per sq. in., bot	0.435	0.33	0.22	0.40	0.30	0.20	0.34	0.26	0.17
θ_a	7.0	5.2	3.5	6.5	4.8	3.2	5.5	4.1	2.7
θ_m	56.2	58.4	60.6	55.1	57.7	60.1	53.8	56.6	59.4
Conventional allowance	8.8	6.6	4.4	9.9	7.3	4.9	11.2	8.4	5.6

Tables V and VI show such calculated values of the conventional allowance for 105 deg. total copper temperature and for insulation thickness corresponding to 6600 volts and 13,200 volts. The figures in each table cover a reasonable range in core temperature and in loss ratio (eddy current factors) to fairly represent current design practise.

In Tables V and VI, the values of core temperature and loss ratio are arbitrarily taken so as to cover the range of current design practise. The temperature of the top coil (θ_t) follows from 105 deg. minus 40 deg. air temperature. The temperature drop through the insulation is then 65 deg. minus the core temperature. Knowing this temperature drop, the watts per square inch follows from the thickness of insulation and heat conductivity of the insulation. (This is assumed as 0.003 watts per inch cube per degree). Dividing the watts per square inch of the top coil by the loss ratio gives the watts per square inch of the bottom coil. The constant K and θ_a and the observable temperature rise θ_m can then be calculated and the conventional allowance obviously follows. The measureable temperature rise (θ_m) is calculated from equation (**9**) which is merely a transposed form of equation (**4**):

$$\theta_m = \frac{\theta_t + \theta_i}{2} + \frac{\theta_t - \theta_i}{2\,L\,R} - \theta_a \qquad (9)$$

These calculated values are based on long machines, say sixty inches and longer. A little consideration will show that, for a *given copper temperature*, the conventional allowance is practically the same for all core lengths. Generators, as ordinarily designed have the same current density and ratio of loss to coil surface for a considerable range of core lengths. This results in shorter-core machines having lower copper temperatures and smaller conventional allowances, as a rule, than longer-core machines. But, if machines of short core length were designed with higher current densities and smaller cooling surfaces so as to have the same limiting copper temperature as long-core machines, the conventional allowances would be substantially the same. Therefore, for the purpose of establishing reasonable values of conventional allowance, core length need not be considered.

It will be observed from a comparison of corresponding columns in Tables V and VI that while the watts

TABLE VII

CALCULATED CONVENTIONAL ALLOWANCES.
13200-Volt Insulation—125 deg. Copper Temperature.
Insulation Thickness—0.25 inch
Calculations are based on long core machines.

Top coil temp. rise	85	85	85	85	85	85	85	85	85
Core temp. rise	30	40	50	30	40	50	30	40	50
Temp. rise through ins.	55	45	35	55	45	35	55	45	35
Watts per sq. in., top	0.66	0.54	0.42	0.66	0.54	0.42	0.66	0.54	0.42
Loss ratio	1.10	1.10	1.10	1.20	1.20	1.20	1.40	1.40	1.40
Watts per sq. in., bot.	0.60	0.49	0.38	0.55	0.45	0.35	0.47	0.385	0.30
θ_a	9.6	7.9	6.1	8.8	7.2	5.6	7.6	6.1	4.8
θ_m	72.9	75.1	77.2	71.7	74.1	76.5	69.5	72.3	75.2
Conventional allowance	12.1	9.9	7.8	13.3	10.9	8.5	15.5	13.7	9.8

per square inch for 6600 and 13,200 volts are different, the values of θ_a, θ_m and conventional allowance are identical. In other words, the conventional allowance with given copper temperature, core temperature and loss ratio, is independent of insulation thickness. For purposes of standardization, therefore, no distinction need be made between low-voltage and high-voltage generators, within the range of generator sizes for which the detector method is specified. The reason for this will be evident from equation (**9**). The only term

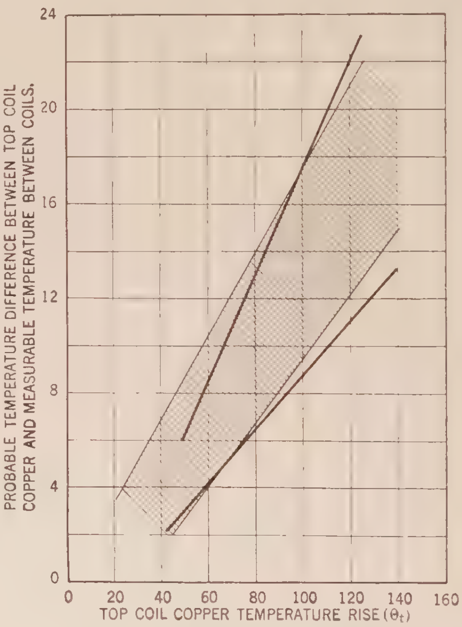


FIG. 10

TABLE VIII.

CALCULATED CONVENTIONAL ALLOWANCES.
13200-Volt Insulation—150 deg. Copper Temperature.
Insulation Thickness—0.25 inch
Calculations are based on long core machines.

Top coil temp. rise (θ_t)	110	110	110	110	110	110	110	110	110
Core temp. rise (θ_i) (assumed)	40	50	60	40	50	60	40	50	60
Temp. drop through insulation	70	60	50	70	60	50	70	60	50
Watts per sq. in. (top coil)	0.84	0.72	0.60	0.84	0.72	0.60	0.84	0.72	0.60
Loss ratios (assumed)	1.10	1.10	1.10	1.20	1.20	1.20	1.40	1.40	1.40
Watts per sq. in. (bot. coil)	0.76	0.64	0.55	0.70	0.60	0.50	0.60	0.51	0.43
θ_a	12.2	10.2	8.9	11.2	9.6	8	9.6	8	6.9
θ_m	94.8	96.8	98.8	92.8	96.4	97.9	90.4	94.0	95.9
Conventional allowance	15.2	14.2	11	17.2	13.6	12.1	19.6	16.0	14.1

in this equation affected by insulation thickness is θ_a. This term, it will be remembered, is

$$\theta_a = K \times \text{watts per sq. in.} \times \text{insulation thickness} \quad (8)$$

But, for constant copper temperature, the product of watts per square inch and insulation thickness is constant, and therefore, θ_a is constant under the assumed conditions.

Tables VII and VIII give similar values of the conventional allowance for higher copper temperatures. Only one value of voltage and insulation thickness is given for reasons just explained.

The results given in these tables give an idea of the probable range in value of the conventional allowance at the limiting copper temperatures for a wide range in values of design factors. These tables could be extended to cover lower and higher core temperatures, and loss ratios, but it is believed that the values chosen are representative of usual design practise, keeping in mind the assumed condition of a fixed copper temperature.

These results are grouped in curve form in Fig. 10. The limits of the cross-hatched area are the maximum and minimum values for each assumed copper temperature rise from Tables VI, VII and VIII. It represents the range of probable values that may be expected in practise.

There have been two propositions advanced as to suitable values of conventional allowance for use in arriving at limiting values of temperature rise for the A. I. E. E. Standards. The first proposition starts with the value of 5 deg. now in the Rules assigning this to Class A insulation temperature limits and doubling this for Class B insulation temperature limits. The second proposition doubles these figures. These two propositions are shown by the heavy lines in Fig. 10. Obviously, the 5 deg.-10 deg. proposition is not adequate to meet the facts, nor is the 10 deg.-20 deg. proposition unduly conservative when it is remembered that the upper limit of values shown in Fig. 10 would be appreciably increased if: (a) allowance were made for increased top coil temperatures caused by the increased eddy current losses in that part of the top coil nearest the air-gap; and (b) if allowance were made for the probability of higher temperatures existing in the individual case than are discovered.

WORK OF THE FEDERAL POWER COMMISSION

A review of the work of the Federal Power Commission during the two years of its operation clearly indicates the practical value of the Federal Water Power Act and the task confronting the Commission. Due to the many years' delay in securing adequate Federal legislation it was but natural that a flood of applications should have followed immediately upon approval of the Act. Nevertheless, during its second year, there have been filed with the Commission applications aggregating a net total of 6,000,000 h. p. of proposed installation. This amount, added to the applications of the preceding fiscal year make a grand total of 321, involving in excess of 20,000,000 h. p. This amount is more than twice the existing water power installation of the United States, and is more than six times the aggregate of all applications for power sites under Federal control in the preceding 20 years.

Nearly one-half of the aggregate of 20,000,000 h. p. is represented by applications upon the St. Lawrence, Columbia and Colorado rivers, upon which, in general, action has been suspended. The St. Lawrence involves international relations and may require a treaty before action can be taken. The Columbia is under investigation by a special board to determine, before applications are approved, the relation between water power, irrigation and navigation upon that stream. Action on the Colorado River is awaiting the findings of the Colorado River Commission, an organization authorized by Act of Congress for the purpose of negotiating between the States within the Colorado basin a compact, in accordance with which the waters of the river may be apportioned among these States.

By the terms of the Federal Water Power Act the Commission is required to investigate all projects applied for to determine whether the structures are safe and properly designed and whether full utilization will be made of the resources of the stream. It is required to make valuations of all properties licensed under the Act and constructed prior to the issuance of license. When declarations are filed of intention to construct dams in streams whose navigable status is doubtful it must investigate and determine whether the interests of interstate or foreign commerce would be affected. It must investigate and pass upon applications for restoration to entry of lands within power-site reserves. It is required to establish a system of accounting to be applied to the operations of its licensees and by means of which the net investment in the properties may always be known. It must assume ultimate responsibility for seeing that licensed projects are properly maintained and that adequate depreciation reserves are established. It has already had many difficult administrative and legal problems to meet in the interpretation of the Act, and it must be prepared to assist in the defense of the Act before the courts.

To perform the greatest task with respect to water powers that the Government has ever had, Congress gave the Commission no personnel other than its Executive, Secretary and engineer officer, but obliged it to borrow for its work such personnel as the departments could spare and were willing to loan.

Under such circumstances the Commission has been obliged to delay action on many important projects, and it has been forced to omit altogether the performance of important duties required by the Act. This is particularly true of valuations. Cases involving approximately $100,000,000 are awaiting action.

Technical Problems of the Tanning Industry

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Member, A. I. E. E.
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The object of this article is to present a composite engineering view of one of the world's oldest industries, for the purpose of directing the attention of the electrical engineer toward some of the more urgent requirements of this industry, which, being primarily electrical, he in particular is peculiarly able to furnish.

The article outlines engineering principles applied in the art of leather making, while views, taken in modern tanneries, show typical manufacturing processes in the two main divisions of the industry. To facilitate visualizing engineering progress in the art, a brief description of manufacturing processes is included as a feature of the treatise. Some recent developments, in the form of mechanical-electrical units, now coming into use, are also illustrated and described; while the article concludes with a table of motor horse power requirements for the individual machine operations performed in making leather.

The authors acknowledge having been assisted in preparing the manuscript with statistics and photographs made available through the courtesy of Tanners Council, New York City, General Electric Company, and the First National Bank of Boston, Mass.

THE art of tanning is basic to the leather trade, and in the list of principal industries, the latter ranks sixth. It can be readily seen therefore, that the tanning industry is of considerable economic importance. Notwithstanding this fact, however, its engineering status, considered as a whole, is comparatively low. It is also true that, compared with many other industries, the amount of capital invested in machinery of production is relatively small.

FIG. 1—POWER-DRIVEN CHEMICAL TREATERS

Fundamentally, the art of making leather dates from the earliest reckonings of mankind, for as emigration from the tropical zones occurred, it unquestionably became necessary for man to provide better protection for his body against the elements than was required in warmer climes. Consequently, he undoubtedly endeavored to utilize the pelts of animals killed for food. He probably found that the raw pelts became hard and brittle, therefore, he possibly tried various means to overcome this difficulty, and thus the foundations were laid for modern tanning processes.

There are two distinct divisions in the art of modern leather manufacture. One consists of tanning the skins of the younger and smaller animals, while the other consists of tanning the hides of the older and larger animals. Skins are usually tanned by the chrome or acid process, but hides as a rule are tanned by the extract or bark process. It takes about eight hours to tan skins by the acid process, but it requires approximately three months to tan hides by the extract process. Skins are usually tanned in a revolving drum arrangement, while hides are in the majority of instances tanned in vats. Fig. 1 shows a view of power driven mechanical devices used in chemical treatment of skins, and Fig. 2 illustrates tanning vats in a sole-leather establishment.

The process through which both hides and skins are put is fundamentally the same. The pelt is first soaked in a soft water solution to make it pliable, and is then limed to loosen the hair, which is subsequently removed by machinery, as is also the superfluous flesh. At this stage of the process, if the pelt is a hide, it is usually split by machinery before tanning, whereas if it is a skin which is undergoing treatment, it is tanned and shaved. The latter process removes the flesh on a skin as is done with a hide

FIG. 2—TANNING VATS

by the fleshing machine. The leather is then finished, after which the area of its irregular surface is measured in a very interesting machine to determine its commercial value.

In the preparation of raw pelts for market today, both chemistry and mechanics are involved. Neither are used however, with anywhere near the effectiveness

that they undoubtedly could be. Progress in this industry has been slow, and is so today. There are many reasons for this fact, the majority inherent to the industry itself. There is much rehandling of bulky material, and methods are needed whereby this can be avoided considerably, or entirely eliminated. Electric conveying and hoisting equipment is conspicuous throughout this industry by its absence, with the notable exception of some large and progressive concerns, and many of the mechanical devices used today remain fundamentally unchanged after more than

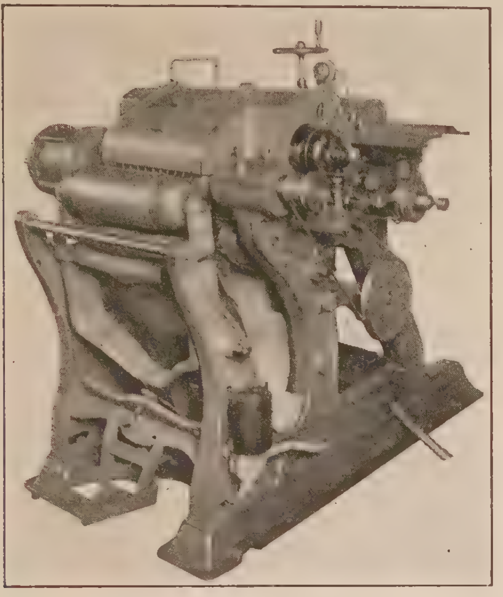

Fig. 3—Shaving Machine

fifty years. This speaks volumes for the opportunities presented to the inventive mind, but sometimes this type of mind requires that it be directed to the objective of its activities.

About one-half century ago it required from nine to twelve months to tan heavy leather by laying it away in bark. The hides absorbed the extract in the bark and were tanned. To-day extract tanning for sole leather is accomplished in three months because the chemist has shown the tanner how to use extracts with much greater penetrating strength without injury to his product. Notwithstanding this fact, however, it is imperative that some means be found whereby extract tanning processes for hides can be accelerated, because the amount of capital invested in pelts laid away to tan is far greater today than in times previous. So-called electric tanning, possibly through an adaption of the phenomenon of electric osmose, may eventually solve this problem, as electric tanning processes of this nature have been experimented with in Germany and England of late, and a considerable degree of success attained. When an electric current is used to hasten and improve the process of tanning pelts, the usual method of procedure has been to suspend each hide between two plates constituting electrodes. The current mechanically carries the tanning liquid through the hide, strong direct currents generally being used in various ways, the principal difficulty seemingly being to compensate for the tendency of electrolytic action occurring, which is neutralized to some extent by periodically reversing polarity.

In any consideration of the mechanics involved in leather manufacture, some mention should be made of what is known as the belt-knife splitting machine, for this unit has been a great factor in the development of the art. This machine consists fundamentally of an endless steel band, with one edge sharpened to act as a knife, which is stretched between two revolving wheels and travels in a plane at right angles to the direction of motion of rotating feed rolls. The pelt to be split is fed into the machine through feed rolls and is severed by belt knife, the latter being kept sharp by power driven emery wheels. It is possible to obtain several duplicate pelts in this fashion, as is done with wood for veneering purposes. This machine was first developed in a crude way over fifty years ago, but is today a really first-class and somewhat intricate piece of mechanism. There are great possibilities

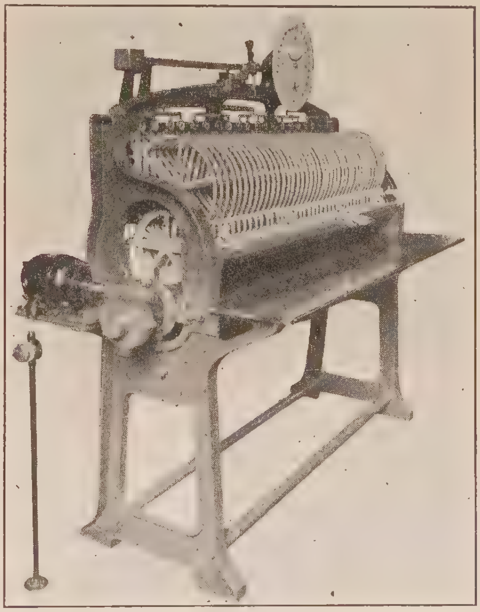

Fig. 4—Machine for Measuring Skins

for increasing the productiveness of these units to a considerable extent by the direct application of either adjustable or multispeed motors, as circuit characteristics dictate. As examples of modern production units of this nature Figs. 3 and 4 are cited. Fig. 3 shows a motor-driven shaving machine, used for removing superfluous flesh on partly finished skins, while Fig. 4 illustrates a motor-driven unit by which the irregular area of leather is measured. Machines of the latter type are the subject of a fifty-page technologic paper issued by the United States Bureau of Standards.

As regards the application of electric motors, this industry is far behind most others, as there are many tanneries in operation today that have not reached the stage of group drive. They are driven by steam engines, with a system of power transmission through line shafting. Direct motor drive has not penetrated this industry as yet to any great extent, and in many establishments at the present time units of from 50 to 75, and even 100 horse power are in use on group drive. Automatic control equipment is almost an unknown quantity here also, while for many reasons it would prove particularly advantageous.

In respect to the power requirements of this industry motors when arranged for individual drive vary in size from one-quarter to thirty horse power, and they should be of the enclosed type, as a rule.

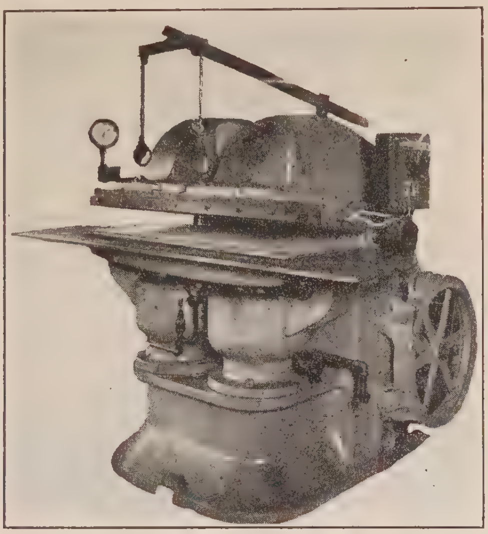

FIG. 5—ELECTRICALLY HEATED PLATING AND EMBOSSING MACHINE

In considering direct motor drive for tanning machinery, there is one characteristic peculiar to this class of equipment worthy of special mention. Much of the machine work done in finishing leather is accomplished with spirally bladed cylinders, some having flywheels attached, and revolving at high surface speeds. Any sudden or periodic variation in angular velocity of the rotating elements of the unit will leave an almost imperceptible series of marks on the unfinished pelt. When the pelt is finished, these marks, left by the blades, manifest themselves in the form of a series of waves closely conforming to the impulses, external to the electrical system, which caused them. Sometimes also, pulsations occurring in an alternating-current system result in vibration on machines of this type, which is extremely detrimental to the operating efficiency of the unit. This is an action similar to hunting, and is very difficult to remedy. However, experiments are now being conducted, incident to development of these units, which will undoubtedly result in the elimination of this trouble. Experience has proved that in some instances properly designed flywheels will help to damp out these oscillations. These conditions should not be confused, however, with that which is sometimes met with when a motor of insufficient horse power happens to be applied to some particular machine.

The majority of the electrical industry is awake to the fact that industrial-electric heat applications comprise a field that is almost inexhaustible. In the tanning industry there are very many opportunities for electrical energy to supplant steam in this respect, with beneficial results. More uniform temperatures can be maintained for heating liquids, drying, and finishing the product. There is considerable machine process work in the tanning industry requiring heat, and electrical energy applied for this purpose would result in a better grade of product being obtained. Fig. 5 typifies a modern unit of this nature, consisting of an hydraulic press, used for plating and embossing leather, which is electrically heated, the temperature being controlled automatically.

The illuminating engineer will find that a large proportion of the tanning industry has yet to receive the

Machine Operation	Horse-power required	Starting duty
Revolving drum work, for skins	7½	Heavy
Unhairing and Fleshing		
Skins	7½	
Half Hides	15	Light
Whole Hides	30	
Hair Washing	2	"
Puer Grinding	2	
Bark Cutting	25	Heavy
" Grinding	25	
Tan bark pressing	3	Light
Scrubbing	5	"
Rolling		
Light Leather	3	"
Heavy Leather	5	"
Brushing	2	"
Setting		
Skins	5	"
Hides	10	
Cheeking	2	"
Union splitting	2	"
Belt-knife splitting		
Skins	5	
Half hides	7½	Heavy
Whole hides	10	
Putting Out		
Vertical Machines		
Skins	3	Light
Hides	5	
Putting Out		
Horizontal Machines		
Skins	5	"
Hides	10	
Shaving		
Skins	5	"
Hides	7½	
Staking		
Stoning		
Blacking	3	"
Glazing		
Ironing		
Buffing		
Whitening	10	Heavy
Embossing	7½	"
Measuring		
Skins	¼	
Half hides	½	"
Whole hides	¾	
Stamping	1⁄3	"

benefits to be derived from modern systems of lighting. In certain respects the illumination requirements of this industry are peculiar, as for instance, that needed for sorting and matching large numbers of individual skins into groups of one or more shades. There is no method of artificial lighting that has been found universally satisfactory for this purpose.

In the tanning industry the engineer will find wide scope, in a virgin field, for the application of his specialized training, because although the industry is old, nevertheless, many of the methods employed are comparatively obsolete, considered from an engineering standpoint. The tanning industry and the engineering profession need each other, and should become better acquainted. Furthermore, it should be noted that electricity ought to play a much more important part in this industry than it now does, and the industry awaits impetus from the engineering profession along lines of increased productive efficiency.

The foregoing table shows the motor horse power requirements for the individual machine operations performed in making leather.

NOTES FROM THE BUREAU OF STANDARDS

LABORATORY FOR TESTING DRY CELLS

The Bureau of Standards has a very complete laboratory for testing dry cells under all conditions encountered in service. The cells are discharged at various rates and for different periods of time and during test are subjected to a wide range of temperature, made possible by the installation of a special refrigerating plant and heating oven. The switches which govern the periods of discharge and recuperation for the batteries are controlled by a master relay operated by a clock. Heretofore only one clock has been employed and no difficulty has been experienced. However, as the apparatus has been used continuously for 2½ years, it was evident that it would soon be necessary to stop the clock for cleaning and adjustment. When the equipment was installed, it was expected that this could be done whenever desirable, but the volume of work has been so great that it has been found necessary to operate the testing plant continuously. Therefore, a second clock has been installed with an automatic device which will throw over the control from one clock to the other in the event of stoppage of either. This places the Bureau's equipment on a very reliable plane, in line with similar apparatus used by the leading manufacturers.

PERFORMANCE TESTS FOR RADIO RECEIVING SETS

Owing to the very large demand which has suddenly arisen for simple radio receiving sets, many retail dealers in other lines of work have taken up the handling of such equipment. It is very difficult for such dealers to decide whether sets offered by the manufacturers are of good or poor quality. The whole art is so new and some of the questions involved are so technical that the problem presents considerable difficulties.

As a consequence, the Department of Commerce, and particularly the Bureau of Standards, has received a great many requests for tests of such apparatus. As it is impossible for the Bureau to conduct all the work of this nature which it would be called upon to perform, it has drawn up rules covering performance test methods which are to be carried out by the Electrical Testing Laboratories of New York in cooperation with the National Retail Dry Goods Association the latter body representing the retailers of radio receiving sets. As the work develops, suggestions regarding improvements of methods of testing will be subject to the approval of the Bureau of Standards.

The tests outlined include: Investigation as to the material and workmanship, the mechanical and electrical design, simplicity of adjustment, strength, sensitivity, sharpness of tuning, wave length range and faithfulness of reproduction in radio telephone reception. The Investigating Committee of the National Retail Dry Goods Association has suggested that from a commercial standpoint it would be of assistance to their members if responsible manufacturers would plainly mark their equipment, indicating the receiving radius of each instrument under every atmospheric condition. Owing to the large number of factors which enter into the determination of the range over which signals can be received with a given set, this is a very difficult problem, impossible to solve at the present time by any brief statement or mark. Strength of signals required by a receiving operator, height and location of receiving antenna, power of transmitting station, its location with respect to other stations capable of causing interference as well as the sensitivity of the particular receiving set must all be considered.

THERMOMAGNETIC ANALYSIS

In any study of the physical properties of materials, the effect of temperature is of great importance. It is well known that at a certain temperature ferromagnetic materials lose their ferromagnetic properties and become very feebly magnetic. It is not so well known, however, that certain more or less abrupt changes in magnetic properties take place at lower temperatures during heating and cooling, and that these changes are often indicative of structural transformations in the material. The Bureau of Standards has designed and constructed apparatus for the purpose of investigating these phenomena. So far as the Bureau is aware, little, if any, work of this nature has been done in this country, although valuable results have been obtained by this method abroad. The operation of the apparatus is now under investigation, but it should soon be available for study of the magnetic transformations taking place in ferromagnetic materials upon heating or cooling.

Discussion at Midwinter Convention

THE PETERSEN EARTH COIL*

(Conwell and Evans), New York, N. Y., February, 16, 1922

W. W. Lewis: In the paper by Messrs. Conwell and Evans it is interesting to note that the only part which gives actual data, that is, Section 3, shows that the Pertersen coil functioned satisfactorily in the manner that it was intended to function, that is, as an arc suppressor. The conditions under which the arc was made were not those usually existing in practise. In the tests an arc was made between switch blades with a comparatively small separation, say a couple of inches or so. Under these conditions the residual current even though small may be enough to maintain an arc. In practise the arc is usually over an insulator with 10 or 12 in. arcing distance and considerable current is required to maintain such an arc even without the neutral reactor.

In the author's comparison of methods of grounding neutrals of systems (page 147) they give for continuity of service first order of performance to the grounded neutral system and fourth to the Petersen coil system. This seems to be a curious inversion of order. That system which is deliberately intended to cause a short circuit and an interruption in case of an arc-over is placed first, and that system which puts out the arc without interruption is placed next to last.

It seems to the speaker that the authors have not made a good comparison between the system with Petersen coil and the isolated and grounded neutral systems. The Petersen coil system really stands between the two. As far as voltage stresses are concerned it is an improvement over the isolated neutral system but not as good as the grounded neutral system. As far as current stresses are concerned it is an improvement over the grounded neutral system, and probably also over the isolated neutral sytem in which an arc-over usually results in a short circuit. It is applicable to moderate voltage systems in which the charging current is low, hence the ohmic reactance of the neutral coil high, so that the reactance of the transmission line itself has practically no effect on the neutral current. Under this condition it is comparatively easy to obtain a balance and the residual arc current may be kept at a minimum no matter at what point on the line the arc takes place. However, on high-voltage sytems or very long low-voltage systems, the charging current is large, hence the ohmic reactance of the neutral coil low. The reactance of the transmission line on the other hand is high so that it is difficult to maintain a balance for arcs at different points on the line and there may be enough residual current to maintain the arc. In no event, however, can the voltage strains be as severe as on an isolated neutral system. In view of these considerations the field of the reactor at the present time would seem to be limited to moderate voltage, moderate length systems.

Some tests were made by the speaker on a 100-mile, 44,000-volt power system in the South equipped with a neutral grounding reactor. The tests were made to approximate operating conditions as nearly as possible. The line was energized and from one conductor to ground was placed a circuit consisting of an oil circuit breaker an insulator or horn gap, a current transformer and ground. Across the insulator was placed a one-ampere fuse. The oil circuit breakers was closed allowing the current to flow to ground, blowing the fuse and causing an arc. The setting of the reactor could be changed by means of taps. All told about 50 arc-overs were made with different settings of the reactor, different lengths of line, pin-type and suspension-type insulators and horn gaps, with the line carrying load and with the line unloaded. In all these tests the coil acted satisfactorily as an arc suppressor even with, in the terms of the authors, as much as plus 60 per cent and minus 20 per cent dissonance. There was in the majority of cases a conspicuous absence of measurable overvoltages such as feared by the authors.

C. L. Fortescue: The theory of the Petersen earth coil is presented in the simplest form when considered in terms of symmetrical coordinates. Thus, for example, at the point at which ground occurs, the system has impressed on it: (1) The normal polyphase voltages which may be resolved into positive and negative phase sequence symmetrical components, and which since their sum at any instant is always zero, can produce no ground current, and, therefore, will have no effect on the choke coil connecting the neutral to ground.

(2) The zero phase sequence voltage tends to cause a flow of current through ground. These currents are of zero phase sequence, and have been termed by telephone engineers residual currents. Under the condition of ground, therefore, we shall have quite obviously a circuit to this zero phase sequence component consisting of the joint capacity of all the wires to ground and the Petersen coil in multiple.

Let us now consider the action of such a system when a ground takes place. Since the impedance of all the conductors in multiple is quite low, there will be an initial rush of charging current. During the period of adjustment, this charging current will set up high surge potentials in apparatus connected across the lines. After the steady condition is attained, the system consisting of the zero phase sequence line capacity and the Petersen coil will oscillate naturally at fundamental frequency.

We have at the instant of zero current, the point of contact at ground potential, and the system oscillating at its natural period, at a zero phase sequence potential equal to the voltage from line to neutral. Therefore there will be no potential between the point at which the ground initiated, and earth and the arc will not be re-established after the first cycle.

Through the dissipation of energy in the system the line will gradually resume its nominal zero phase sequence potential, which, if there be no dissymmetry in the system, will be zero.

So far the system appears to be ideal, but let us examine it still further:

(a) The ground current is not the contact current, but will be very large, especially in large cable systems, where the capacity of all the conductors to ground has a large value. The ground current is the capacity current when all the conductors are charged to a potential above ground equal to the Y voltage. The duration of this condition depends upon the closeness of the resonance, thus if there were no losses in the system during resonance, the time would be prolonged indefinitely. The interference or residual currents, are, therefore, not small and they extend through the system for its complete length.

(b) Unbalanced impedance in the lines, will cause under load conditions a zero phase sequence e. m. f. in the system to which the Petersen earth coil and the line capacity form a resonant system. If the losses are low, there will be nothing to prevent a high potential being induced in the system. If a short circuit takes place between lines in which there is dissymmetry, the potential to which the system may be raised is very high.

Breakdown of lines, of transformer, generators and motors will all produce high potential rises, and a fault, which, with a dead grounded neutral would be confined to a narrow scope, may be spread to other parts of the system.

(c) In a large interconnected system, we would have the undesirable condition that a ground on one feeder would raise the potential of the whole system. This might result in dangerous conditions for the users of power where their circuits are not grounded.

(d) The transient condition at the installation of the short circuit may cause severe surges in connected inductive apparatus.

(e) From the point of view of electrical apparatus in general, the system is undesirable. It is introducing an uneconomical system to take the place of a standard of power transmission and distribution, which has been established and is the result of a great deal of experience and careful thought.

It should be borne in mind that in the long run, the system

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*A. I. E. E. Journal, Vol. XLI, 1922, February, p. 140.

that is most favorable to the power producer and user will also work out best for the telephone system.

The dead grounded neutral system has become standard. This condition has not been reached by haphazard means, but it is the result of a long history of bitter experience with isolated systems.

The speaker was among the first to recognize the advantages of the dead grounded neutral, and has lived to see the opinions of transmission engineers come around to this point of view as the result of actual experience in the field. We must guard against permitting the alleged advantages, in a narrow field, of such a device as this one under discussion taking hold of our imaginations. If it has applications in a certain field, let us define this field as closely as necessary to prevent misapplications of it, which may lead to serious trouble in the future.

In considering the relations between the power and telephone interests, we should guard against concessions to the latter which will hold back the development of the power resources of this country. One of the essential requirements for furthering the rapid development of power is a stable system of transmission and distribution. This can be obtained only with a dead grounded neutral system. The general recognition of this system as the standard will lead to standardization in line materials, insulation, transformers, etc., so as to produce better performance at the least cost.

In considering the relative merits of the two cases in the controversy, we should keep in mind the ultimate investment, and the system which will make this the minimum will be best suited to our needs.

H. M. Trueblood: The authors speak of resonanting the earth coil with the sum of the currents through two of the line capacities to ground. One ordinarily thinks of resonance as a condition obtaining between two reactances, rather than between a reactance and a current. It would possibly lead to confusion, however, if the statement were taken to mean that the earth coil inductance is to be resonated with the sum of the capacities to ground of the two non-grounded phases. The earth coil inductance should be resonant with the sum of the *three* capacities to ground, that is, if with solidly grounded neutral, the three Y-connected legs of the transformer bank be energized with three equal fundamental frequency voltages, all in phase, the quadrature component of the neutral current should be equal in magnitude to the same component of the current taken by the reactor when energized by one of the same three voltages. This current component will, however, also be equal to the sum of the currents taken by *two* line capacities with the third phase grounded when the system with neutral isolated is energized three phase at the same star voltages as before, provided the voltages and capacities to ground are balanced. The reason is of course that in the latter case the reduction in total capacity to ground is exactly counter-balanced by the higher voltages to which the two capacities are subjected, combined with the effect due to their phase displacement (60 deg.). If the neutral is grounded through a correctly tuned reactor, instead of isolated, the quadrature components of current (referred to the star voltage of the grounded phase) through the line capacities and through the reactor annul each other at the fault, so that, as stated in the paper, the minimum reading of an ammeter carrying the fault current indicates correctness of tuning. An ammeter located as shown in Fig. 5 would carry a charging current for wire-to-wire capacity as well as the fault current.

This equality of the quadrature current taken by the reactor at star voltage to the sum of the currents taken by the capacity to ground of two phases, with the third grounded, is what constitutes the "parallel resonance" of the system. As is explained in the paper, it is this condition, which exists only when one phase is grounded, that operates to extinguish the arc to ground. The "series resonance" condition is equally fundamental to the operation of the reactor. As is perhaps not quite clearly explained in the paper, it is this condition which becomes operative to prevent the restriking of the arc, after the condition of parallel resonance has brought about extinction of the arc, and has thereby ceased to exist. It is because of this "series resonance" that the current taken by the total direct capacity to ground at star voltage is equal to the quadrature reactor current at the same voltage, as previously pointed out. The transition from the "parallel" to the "series" resonance condition takes place when the arc goes out, and is accompanied by no appreciable transient due to fundamental frequency, if extinction occurs when the fundamental frequency current passes through zero. At this instant, the fundamental frequency charges and currents in the system have the proper values for both types of oscillation, except perhaps for slight deviations due to system losses.

In their discussion of dissonance the authors might be understood as stating that the phase which had been grounded might within a few cycles be subjected to a voltage slightly less than twice the star value, with dissonance and with either high or low loss. Over-voltage due to dissonance will be more pronounced with low than with high loss. The resultant voltage shown in Fig. 8 can hardly be described as slightly less than twice normal. It would seem to be rather less than 1.4 normal, and would evidently be greater if the damping were smaller.

In referring to the trouble which may be produced by voltage vibration on a transmission line, the authors presumably do not mean that the effects would be worse than with isolated neutral under similar circumstances.

The experimental result showing that with a single-phase set-up a voltage to ground 250 per cent of normal, *i. e.*, 125 per cent of line voltage is obtained on the sound wire, checks quite well with some theoretical calculations I have made regarding this matter. It would be interesting to know whether similar tests with free neutral were made, and if so, what results were obtained. I have been unable to discover any theoretical reason for expecting greater over-voltage with the Petersen than with the free neutral system from transient effects rising from the redistribution of energy referred to in the paper. With the Petersen system, the principal transient term is nearly the same as with the free neutral system, and there is an additional non-oscillating term due to dissipation in the circuit consisting of coil and grounded transformer leg. This, however, is insignificant compared to the other, so far as the voltage from a sound phase to ground is concerned.

The authors state that with "a 'make and break' through the accidental arc, the transient voltage may rise to slightly less than twice line voltage." It is not quite clear just what is intended here, but if a single "make and break" is referred to it seems unlikely that the highest voltage of a sound phase to ground would exceed 125 to 150 per cent of line voltage.

An oscillating system responds with large effect only to impressed forces of approximately its natural period. It is therefore not easy to see why lightning is given as a possible source of resonant effect in the "series resonant" circuit. As to inductive effects due the action of currents belonging to the system itself, which I presume are what is referred to in mentioning "mutual induction," "unsymmetrical impedance under load" etc., I think these will be relatively small so long as the currents are confined to the line conductors and are not of excessive magnitudes, *i. e.*, are not short-circuit currents. When the currents are confined to line conductors the inductive effects of interest in this connection arise from differences in the mutual inductances between line wires, and the distribution of current among the latter is thus not a factor of great importance. In some cases I have calculated, the effect from balanced and symmetrical currents of about full-load magnitude is nearly the same as from a single-phase current of the same magnitude per wire. Neither was large. There is a further reason why the effects of such induction in the series resonant circuit is lessened. It is

that the induction does not take place directly in this circuit. The induced voltage is distributed linearly along the circuit. So is the capacity of the resonant circuit. The two are therefore not directly in series. If the system consists of a single line, the effect of this factor alone is to reduce the current in the resonant circuit by 50 per cent of what would be if the induction occurred directly in series. Furthermore, this current can be reduced to an insignificant amount by transpositions. The effects of short circuits cannot, of course, be entirely avoided by transpositions. In a single line system of considerable kv-a. capacity, it would seem that the neutral might be raised to a considerable fraction of star voltage above ground by a single-phase short circuit, under circumstances favorable to the production of such an effect. In a multi-line radial system or in an interconnected network, the effect of a single-phase short circuit would be much smaller.

Unbalance of line capacities probably produces the most important effect of any non-accidental sources of induction. To keep their effect small it is necessary that the ratio of the vector sum of the three admittances to ground to their arithmetical sum be small compared to the ratio of the resistance of the coil to its reactance. This should usually be obtainable with only a modest amount of transposing.

Induction from the voltages of neighboring power circuits would not be in the series circuit except in the rather rare case of a practically complete parallel to all lines of the system on which the coil is installed. It should therefore usually be of relatively small effect, except possibly when the neighboring system is in trouble.

It is difficult to verify the statement that "the induced voltage may be only a small percentage of the star voltage, but if the resistance of the system is small, and if resonance occurs, the voltage between one wire and ground may be many times the star value." Assume a ratio of 1/10 for the coil resistance to its reactance and assume also that the "small percentage" of the star voltage is not more than 10. The voltage thereby produced between wires and ground would be about one times star voltage. If it were exactly in phase with one of the line voltages to ground, the highest resultant line voltage to ground would be about twice star voltage. By reducing the coil resistance-reactance ratio and increasing the "small percentage", this might be brought up to 3 times star voltage, but it would be hard to get it higher. Seven to eight per cent of star voltage in the series resonant circuit would be a liberal estimate for the voltage due to capacity unbalance, even if the line is not transposed at all.

The authors describe an interesting series of tests and advance explanations of a number of effects that were observed. They have not, however, collected into a separate series of statements the conclusions which they draw from this experimental work, and it is difficult to decide just what inferences one is expected to make. The discussion of film 25 on page 147, and also in the fine print under Fig. 13, seems to indicate that the authors believe that excessive or dangerous voltages between neutral and ground must have occurred, because of the large instantaneous values of reactor current. On page 146, however, they state that "the magnitude of the current through the earth coil indicated that the maximum value of voltage between neutral and ground was about 1.3 times normal." If this means 1.3 times star voltage, it seems hardly larger than might be expected even without an arcing ground. I would like to ask whether the authors do not suppose that the excessive currents observed in the fault and in the earth coil, in the arcing test and also in some of the other tests, are due to saturation in the transformers which were used in the connection from neutral to ground. Apparently the 13.2 kv. transformer was worked at some 20 per cent above normal voltage, with one phase grounded, even under steady state conditions, and of course the exciting current would be considerably larger than normal with this excess above normal voltage. The figure given for reactor current in the test for adjustment of resonance appears to indicate some effect due to saturation.

It seems to me that the drawing of conclusions of general applicability from these tests is very considerably complicated by the presence of a factor so difficult to evaluate as over-saturation of iron. Some of the other peculiar effects shown in film 25 may be connected with it. Certainly it must be agreed that this film is rather difficult to follow. For instance, in the author's discussion of the non-oscillatory shape occasionally present in the trace of one of the currents on this film, they are apparently talking about the coil current, yet the oscillogram looks as though it were the fault current which has this characteristic.

On page 145 the authors speak of a "noticeable overcharge during the transient which occurred on opening the fault as shown by the voltage, phase 3 to ground, in films 15 and 16." The trace of this voltage is too dim to be seen on film 16 and is not present on film 15, unless the film is incorrectly labelled. Presumably the effect to which they refer is that which appears in the phase voltages on the two films, however. It is due, I believe, to inexactness of tuning. It may be seen that the frequency of the coil voltage in film 16 and the coil current in film 15 slows down as soon as the free oscillation begins. The ratio of the frequency of this oscillation to that of the fundamental appears to be about 8:9. If the tuning were exact, the reactor voltage in film 16 should be in the same or the opposite phase (depending on the polarity of vibrator connections) to the voltage on the phase from which the fault has been removed. The two appear to coincide at about the third maximum after the beginning of the free oscillation, and this apparently produces the overvoltage on phase one.

Livingston P. Ferris: I have given the Petersen earth coil some consideration from a different point of view from that of the authors and have had an opportunity to see several of the European installations. These I will describe very briefly and then outline some facts showing the effect of the device on induction in neighboring communication circuits.

Rome Municipal Line—22 miles—Twin Circuits. Two 30,000-volt, 3-phase 42-cycle, 7500-kv-a., star-connected generators are connected direct to line. The transformers at the Rome end are delta-delta. The system was first operated isolated. Trouble developed with the insulation of generators at times of line faults. A Petersen coil was installed in the Castelle Modame Station in January 1920. A visit to this station was made in July 1920. The chief of the station was questioned at length and some test records were examined. He was convinced that the action of the Petersen coil had been beneficial. This is not a typical installation, but if its testimony can be believed, it is against the presence of excessive over-voltages as otherwise no benefit would have resulted. This installation is decribed by Lombardi in *L'Ellectrotechnica*, August and September, 1920.

Alta Italia-Line—65 Miles: 42-47 kv., 3 phase, 21,000-kv-a. Two star-connected auto transformers make slight changes in voltage between generating station and receiving station in Turin. A Petersen coil is installed between neutral of the star-delta receiving transformers and ground. It had been in service 1½ years at the time I interviewed Ing. Palestrino and saw the coil in October 1920. Previous to installation of coil, the neutral was isolated. Ing. Palestrino considered that the coil had been beneficial in reducing interruptions. A new coil of larger capacity was then under construction to replace the original. It was proposed to apply a Petersen coil to a 75-kv. circuit. The Alta Italia installation is described by Palestrion in *L'Ellectrotechnica* for July 5, 1920.

A number of other installations exist in Italy where the system is being given serious study by a committee of the I. E. A., headed by Prof. Lombardi who has published a number of articles on its theory and application. It will be of interest to

know that Petersen, according to Lombardi, does not advocate exact resonance, but rather that the coil should have 10 to 15 per cent less reactance than the line. This was mentioned in connection with a discussion of unsymmetrical capacities and I suggested to Lombardi that the difficulty arising from such dissymmetry could be easily overcome by transposing the circuit. To illustrate how practical this is, the following figures are presented, based on experiments on a 36-mile power circuit of vertical configuration (one of the most unbalanced types). Residual voltage, fundamental frequency, isolated neutral, untransposed line, 6.9 per cent of voltages between wires. After two transpositions were installed on poles nearest third points, the residual voltage was too small to measure, but certainly less than 0.6 per cent. The residual voltage in this case is a measure of the capacity unbalance.

Swiss installation: One of the most extensive and interesting applications of the Petersen system is in Switzerland. Here it is applied with a number of coils to a very high-voltage cable and transmission line network. The coils in this case have air cores whereas in all other cases they had iron cores. Here apparently the purpose is to reduce damage to cable at times of fault by limiting fault current to the relatively small loss current rather than full charging current to ground in case of isolated systems or short-circuit current in case of grounded system. Of course, with a cable one can scarcely expect a fault to heal like some flashovers on a line. A high-voltage cable network would be about the last place to apply a Petersen coil if there were danger of serious transient over-voltages. I refrain from speaking more specifically of this Swiss case as the engineers responsible have not yet published their views. I have reason to expect they will do so in the near future.

No information which I have been able to obtain on any European installation would warrant the rather vaguely stated final conclusion of the paper. It would seem proper that the authors should submit more specific evidence in its support.

Now as to the bearing of this device on inductive interference problems, a matter ignored by Petersen and all other Europeans

COMPARISON OF DIFFERENT METHODS OF GROUNDING THE NEUTRAL

From Standpoint of Residual* Voltages and Currents

Method of grounding neutral	Under abnormal conditions ground on one phase		Under Normal Conditions: Fundamental		Under Normal Conditions: Harmonics not of triple series		Harmonics of triple series
	Residual voltage	Residual current	Residual voltage	Residual current	Residual voltage	Residual current	Residual voltage and current
1 Petersen Coil	$\sqrt{3}\,E$	Max. $\frac{E}{\sqrt{3}}\,l\,\omega\,C_g$ at Coil. Zero at other end of line.	May be large if capacities are unbalanced to ground. Can be made unimportant if line is transposed.	May be large if capacities are unbalanced to ground. Can be made unimportant if line is transposed.	Practically same as (2) 104%— 5th 100%—29th	Practically same as (2)	15%—3 rd 1/2%—27th
2 Infinite Impedance (Isolated)	$\sqrt{3}\,E$	Max. $\frac{E}{\sqrt{3}}\,l'\,\omega\,C_g$ at fault, between 50% and 100% of max. for (1). Zero at ends of line.	Larger than (3) or (4) but smaller than (1) $3\,E\,\frac{C_r}{C_g}$	Zero	Depends on unbalance of line capacities. Can be made small as desired by transpositions. Relative magnitude 100%.	Much smaller than (3) Zero at ends of line.	Zero
3 Zero Impedance (Solid Ground)	$\frac{E}{\sqrt{3}}$	Short circuit current, same everywhere between fault and neutral. Large compared with (1) or (2).	Zero except for dissymetry in transformer voltages.	Smaller than (1) when due to unbalanced capacities. With multiple grounds may be large.	Zero except for dissymetry in transformer voltages and slight effect of capacity unbalance.	Depends on unbalance of line capacities and dissymmetry in transformer voltages.	Depends on transformer design rating excitation and line constants. Relative magnitude 100%.
4 Moderate Resistance Rm Less than Rc generally larger than faulty phase impedance	$\sqrt{3}\,E$ Max. value for low impedance fault.	$\frac{E}{\sqrt{3}\,R_m}$ Small compared with (3).	Much smaller than (1) (2) or (5).	Same as (3) or slightly smaller.	Approximates (3) Much smaller than (1), (2) or (5).	Approximates (3) Larger than (1), (2) or (5).	Smaller than (3) much larger than (1). More effective at higher frequencies.
5 Critical Resistance Rc	$\sqrt{3}\,E$	$\frac{E}{\sqrt{3}\,R_c}$ Usually smaller than (4).	Larger than (3) or (4) but usually smaller than (1) or (2).	Smaller than (4).	Slightly larger than (3) or (4). Smaller than (2).	Lies between (3) and (2) depending on extent of system.	Smaller than (4). Larger than (1) at least at higher frequencies.

* —Vector sum of voltages to ground or vector sum of line currents.

E —Normal voltage from wire to wire.

C_g—Total direct capacity to ground per mile of 3 wires in parallel.

l —Length of line in miles.

l' —Maximum length of line on one side of fault.

C_r—Residual capacity = combination of 3 direct capacities in 120° relation.

and not mentioned by Messrs. Conwell and Evans. To appreciate this it is necessary to make comparisons with other systems of grounding or not grounding power circuits. To facilitate such, the foregoing table is presented. It compares the residual voltages and currents for different methods of grounding the neutral of a power circuit and for different conditions, normal and abnormal. As the balanced currents and voltages are inherently the same, irrespective of the condition of the neutral, they do not enter into our comparison of different systems. The possible inductive effects of corresponding factors of the several systems are, of course, directly proportional to the magnitudes of those factors in their respective systems.

From the above table, it will be noted that the Petersen system will, under conditions of a ground, produce inductive effects from voltage unbalances of the same order of magnitude as those produced by an isolated system, and that these are approximately three times as great as would be produced by a system with neutral solidly grounded. Electric induction from this cause will affect neighboring open-wire telephone lines, but will have no effect on underground telephone circuits, and relatively little effect on telephone circuits in aerial cables, if the sheath is grounded. The magnetic induction from the residual current will obviously be very much greater in the case of the grounded neutral system than in the case of a system grounded through the Petersen coil or isolated. The magnetic induction will furthermore affect underground as well as open-wire circuits. Theoretical studies and experience combine to indicate that the effects of induced voltages in case of a fault to ground, considering both electric and magnetic components, are more severe with the solidly grounded neutral than with the isolated system except perhaps in case of long exposures involving very high-voltage power circuits. This is largely because of the greater transfer of energy by magnetic induction with the grounded neutral. From a theoretical study of the Petersen coil, it would be expected that the effects under abnormal conditions would be quite similar to those produced by isolated systems, except that the tendency to prevent the formation of arcing grounds would constitute a considerable advantage for the Petersen system, as the results of an arcing ground are proportionately as undesirable from the standpoint of neighboring telephone circuits as from the standpoint of the power system.

Under normal load conditions, the principal effect of the Petersen coil is practically to suppress the inductive effect of such triple harmonics as may arise from the transformers in a grounded neutral system, thus making it approximate the isolated system as regards the absence of induction from triple-harmonic residuals. So far as harmonic residuals not of the triple series are concerned, these remain practically the same with the Petersen coil as with the isolated neutral, and are capable of reduction by the same method, namely power circuit transpositions.

Detailed comparisons of inductive effects from residuals under abnormal and normal conditions and including systems employing a resistance in the neutral connection, may be based on the table. It should be remembered that under normal load conditions, the inductive effects of the balanced components must also be considered. Under abnormal conditions, the inductive effects of the balanced components are generally masked by the much larger effect of the abnormal residuals.

Under abnormal conditions, the magnitude and phase of the residual current or unbalanced current to ground at all points in an isolated network or one grounded through a Petersen coil, may be very closely determined by considering all three phases in multiple and replacing the fault by a single-phase generator connected between the 3 multipled phases and ground, whose voltage is equal in magnitude but opposite in phase to the normal voltage of the grounded conductor and whose internal impedance is equal to that of the fault. If we are interested in the actual currents in the several phases, these may be obtained by combining the unbalanced currents with the normal load and charging currents. This method of analysis is very helpful on occasions and leads to quick results.

In discussing the effect of the Petersen coil on the selective action of relays, the authors point out a real difficulty but may we not hope that if the advantages of the Petersen coil are sufficient in other respects this difficulty may be overcome. The authors, themselves, suggests a means of avoiding this difficulty if not of overcoming it, by shunting the Petersen coil with an automatic switch which may either solidly ground the neutral or cut in any desired amount of resistance. The authors claim that such a combination system would punish an insulator more than would be the case if a solidly grounded neutral were employed. It is not apparent that there would be much difference or that it is of importance. I would suggest in this connection, that if instead of reverting to a solidly grounded neutral, a moderate resistance were cut in by the switch, not only the insulator in question would be spared from punishment but, also, neighboring communication circuits. For all those cases which the Petersen coil may clear without interruption, both the power circuit and neighboring communication circuits are the gainers. It remains to be determined by experience whether cases of the latter kind will be a sufficiently large proportion of the total to warrant the use of a combination system.

I wish to make it clear that I do not regard the Petersen coil as a panacea for all inductive difficulties but merely that it is of sufficient importance to warrant a comprehensive, and preferably cooperative, study from all points of view, to bring into light all the pertinent facts by which it must be judged. As yet, we have no experimental data bearing particularly upon inductive interference but, of course, data as to its effect on the power circuit give us a good guide as to what we may expect since the two are intimately related. Primarily and fundamentally, the device must satisfy power circuit requirements. If this is done, we should then, in particular cases where inductive interference is involved, give due weight to its advantages or disadvantages from this and other standpoints along with those of all other systems in arriving at a decision as to which should be used. I think this is a basis upon which we may all agree.

F. C. Hanker: Most of the comparisons made today have been made with the free neutral system. Such a basis of comparison seems rather surprising when one considers the actual practise in power systems, the growth and inter-connection of systems. A number of years ago it was felt that the size of a transmission system or the extent of a net work would be limited on account of the effect of arcing grounds, a phenomenon incident to the operation of a free neutral system. Since that time, the tendency has been more and more toward the grounded neutral system and for that reason I believe that the basis of comparison of power systems would be a grounded neutral system.

The Petersen coil has certain advantages if it could be worked in with existing power systems and if it did not in any way limit the expansion of power service. With respect to continuity of service, which is really the criterion of best service, which would be of advantage to the power company and customer, our experience has shown that the grounded neutral system has had a far better record than was the case in the days of the free neutral system. This means that we must recognize the possibility of arc ground disturbances when the characteristics of a free neutral system are approached. It also follows that we must devise and develop protective devices that will take care of such disturbances, and not put a handicap on power systems and limit their development. It has been stated a number of times that there are possibilities of protector breakdown and fire hazard and other difficulties as a result of magnetic induction. Experience has not always borne out these possibilities. When power systems are compared the basis should be on what promises to be the best service conditions to the customer, taking into account future growth and interconnection of systems.

The study of the earth coil indicates that the application is limited. High-voltage transmission lines or extensive cable systems are not favorable for the application of the earth coil because of the high charging currents involved. The earth coil is not suitable for application on systems where graded insulation or auto-transformers are employed, because the neutral point cannot be solidly grounded. Complicated networks are not favorable for the application of the earth coil due to the difficulty of securing isolation of faulty feeders. The most suitable conditions for the application of the earth coil are on moderate voltage systems of rather limited extent, particularly those where duplicate transmission lines do not exist. It appears, therefore, that the earth coil is not suitable for general application on power systems.

H. S. Warren (communicated after adjournment): The "Petersen earth coil," so-called, has an important effect from the inductive interference standpoint. One of the most difficult problems in inductive interference-prevention is that of avoiding the severe surges of high voltage induced in a telephone circuit when a fault develops on a paralleling power circuit. Such a situation will be clear from the following diagram. (Fig. 1).

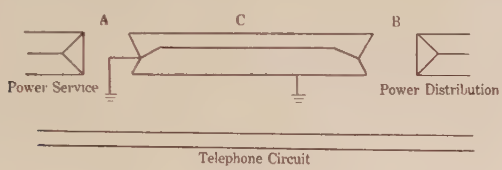

FIG. 1

The transformer at A, supplying power to the transmission circuit is shown with the neutral of its high-tension winding solidly grounded. Under conditions as shown, with normal load and the circuit balanced, no current of fundamental frequency will flow through the neutral connection. When, however, the insulation fails, as at C, grounding one phase wire through the fault either solidly or through an intermittent arc, the voltage of that phase is suddenly short-circuited through the grounded phase wire, fault, and earth back to the neutral, thereby causing a large current through the loop consisting of the faulty phase and earth. By electromagnetic induction this large current through the grounded loops sets up a large voltage along the wires of the paralleling telephone circuit. These suddenly induced voltages produce various harmful effects, the most serious of which in recent experience is that of acoustic shock to telephone operators.

Now as to the bearing of the Petersen earth coil on this matter. If the Petersen coil were used in the neutral ground connection, the current at such times of fault, through the fault and the earth loop, would be relatively small and thereby the severe electromagnetically induced surges avoided. It should perhaps be added that the foregoing has in view more particularly transmission lines of lower voltage, as compared with the highest voltage lines now in operation.

If the resistance were inserted in the neutral ground connection the short-circuit current through the fault would be, of course, less than with a solidly grounded neutral. By making the resistance high enough the induced voltage can be made as small as desired. The method of high resistance in the neutral ground connection is therefore an alternative to the Petersen reactor as a possible solution of this inductive interference problem.

If the use of the Petersen earth coil proves feasible from the power standpoint, it will be of considerable benefit from the standpoint of telephone service where parallels exist. To a certain extent the interests of the two services are alike for if the Petersen coil were objectionable from the power standpoint by reason of causing large overvoltages which break down the power line insulation, it would for the same reason be objectionable from the standpoint of surges induced in neighboring telephone circuits.

It is fundamental, of course, that the Petersen coil cannot be used under conditions where it is incompatible with the service requirements of the power company. It would be fruitless to employ a preventive of interference to telephone service which would introduce interference to power service. However, the possibilities of adapting the Petersen earth coil to practical conditions encountered in this country have not yet been fully studied and it is obvious from the remarks of several speakers that some power engineers are more optimistic regarding the Petersen coil than the authors of the paper. If there is a lack of full understanding as to certain aspects of the functioning of this device and the effects and reactions which it produces under different conditions, the engineers interested should investigate these questions.

A. E. Silver: From the results brought out in Messrs. Conwell and Evans' paper, from the discussion offered and information from other sources, it is clear that the application and performance of the device is dependent upon several power systems characteristics, all subject to variation through a wide range for different systems and, for any specific system, each subject to variation, in a degree that cannot be predetermined, of such factors as total length of circuits interconnected, quality of line insulation changing with dust deposits and atmospheric conditions, and others that must be taken into account in adjusting the earth coil. The coil can function ideally, if at all, for only one assumed set of these conditions. Furthermore, the disadvantages that have been pointed out must be kept clearly in mind, especially the danger to apparatus insulation from rises in voltage to ground. Having learned, after much theorizing through the hard and costly school of experience, the value of the dead grounded neutral in protecting insulation and draining off abnormal potentials from our power systems, we must not compromise this essential safeguard without sufficient and well weighed reasons.

It would appear that no rule can, at this time, be set down of general practicability and benefit from this device. In the main any system under consideration must be taken up for individual study and determination as to successful performance, safety to apparatus and economy. Theoretical study alone, no matter how great, is inadequate and this determination cannot be made with assurance until sufficiently extensive experience with installations under service conditions has been gained to give a good knowledge of the range of conditions under which the device will function successfully without sacrificing safety of apparatus or imposing other undue disadvantages. It may be found that the limits of beneficial application will embrace only small ranges.

It therefore seems to me that operating results should be observed carefully and continuously for any installations of the earth coil now in service. While experience with additional installations is desirable it would, however, seem good engineering judgment that any early installations be added only in those situations that appear to offer the most favorable conditions.

Mr. Ferris in his discussion, has, very properly, touched upon the relation of this device to the problem of inductive interference control, and presented some of the theoretical aspects concerned. In this regard, also, the earth coil seems susceptible of extensive theoretical deduction as to results, but I believe that most of the foregoing points raised concerning it as a power system protective device, and other similar considerations, are applicable here and that conclusions cannot be drawn as to practical results, either beneficial or adverse, except from observations of actual performance.

To properly determine its effect upon telephone circuits, various telephone system characteristics as well as those of the power system, must be observed and given due weight. Under abnormal conditions in the power system, which I understand

is the situation offering opportunity for possible benefit from the coil, the practical need for it has a very intimate relation to the characteristics of the telephone protective devices.

Any studies or tests to determine the value or need of the earth coil as an inductive interference control device should, as Mr. Ferris suggests, be made cooperatively and with all information bearing upon the subject taken to account.

In this connection it seems pertinent to inquire the status of any relatively recent research work by the telephone companies upon their protectors that may bring improved characteristics, particularly as the arrester types with which engineers in general are familiar appear to have undergone no essential change for many years.

R. D. Evans: Mr. Lewis has questioned the order of preference of the various methods of grounding the neutral of power systems when viewed from the standpoint of continuity of service. The essentials for providing for continuous service are:

1st. Employment of measures for prevention or reduction of disturbances which may result in failure of apparatus lines on equipment.

2nd. The prompt isolation of apparatus lines on equipment in case of failure.

Relay protection for the isolation of faulty parts of the power system has developed to a much greater extent than means for the prevention or reduction of disturbances. Consequently, the dependence for continuity of service is rightly placed on adequate relay protection in connection with multiple lines. For this reason, preference is given to the grounded neutral system because it best insures desired relay operation. It is generally recognized that faulty part of a power system should be promptly isolated to prevent interference with continuity of service. The earth coil system does not permit adequate relay protection and, therefore, this system does not deserve better than fourth place in the order of preference, for the various methods of grounding from the standpoint of continuity of service.

With reference to the question for the conditions of resonance mentioned by Mr. Trueblood, it is to be pointed out that this condition may be determined in two ways:

1st. By adjusting the reactor to obtain a minimum current through a fault on one wire as indicated for the single-phase system of Fig. 2 of the paper.

2nd. With normal conditions on a power system to induce a voltage in series with a series resonance system and adjust a reactor for maximum current through it.

That these two methods of obtaining resonance are equivalent may be seen by the following analysis:

If a voltage be induced in series with the reactor exactly equal to the voltage between one conductor and the ground, that conductor may be grounded without changing conditions. The introduction of a voltage on this system cannot affect the capacities, and consequently, the two conditions for obtaining resonance described above are identical.

Under the conditions shown in Fig. 25, there was undoubtedly some effect of saturation of the iron in the transformer employed to connect the earth coil in the power system. Mr. Trueblood appears to believe that the maintenance of the arcing condition was due to saturation which produced dissonance, causing the large fault currents. It appears more logical to believe that the excess voltages were produced by the arcing condition and that the excess voltages were limited by the saturation of the transformer to approximately 1.3 times normal voltage.

If the earth coil consisted of an air core reactor, higher voltages would be produced accompanied probably by relatively smaller fault currents. The use of the transformer in such a manner to reduce excess voltages has been advocated in Europe by those favoring the earth coil system.

Mr. Trueblood's careful reading of the paper has revealed two statements which we would like modified. In case of a single make and break, the voltage between the sound wire and ground may rise to slightly less than 2.73 times normal voltage between line and neutral instead of slightly less than twice line voltage. For the single-phase system the voltage of the sound conductor may rise to slightly less than three times normal voltage to ground. The context of Fig. 5 indicates that the diagram was drawn incorrectly. It should be as shown in the accompanying diagram, Fig. 2.

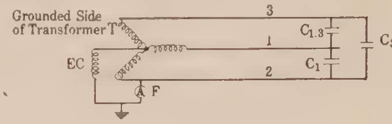

Fig. 2

Mr. Trueblood in his discussion appears to minimize the importance of excess voltages arising from abnormal conditions. He states that excess voltage between sound wire and ground will not exceed 125 per cent to 150 per cent of line voltage, these voltages correspond to 216 to 260 per cent of normal voltage between line wire and ground. Possibilities of excess voltages on the free neutral system were pointed out but the value of the dead grounded neutral in protecting insulation and draining away abnormal potentials was learned only through the costly school of experience, as Mr. Silver has just pointed out. The Petersen Earth Coil System in general approaches the characteristics of the free neutral system and both are subject to abnormal voltages. In this connection, we wish to refer to a discussion published in the E. T. Z., March 10, 1921, in which Dr. Roth cited a case where an open circuit on which wire of a 50,000-volt system produced voltages of 150,000 volts to ground due to the action of the earth coil. He further stated that these voltages, as might be expected, caused the failure of the transformer. The significance of this discussion lies in the fact that the series resonant relation is inherent in the earth coil system and that voltages may be induced in the system due to conditions such as the presence of other circuits and abnormals which can scarcely be avoided in practise. The tendency to minimize the importance of excess voltages would be as dangerous with the earth coil system as with the free neutral system.

Mr. Ferris has described some European installations of the earth coil including the opinions of the operators of the power system. In this connection, it is to be pointed out that the improvement in operating conditions secured by the installation of an earth coil is not significant unless compared with the operation of a grounded neutral system.

The inductive interference aspects of the earth coil system were considered by Conwell and myself during the preparation of the paper, and at that time, was deemed inadvisable to bring that phase of the subject before the Institute. The chief advantages of the earth coil from the standpoint of inductive interference are in comparison with the grounded neutral system. Two of the principle advantages are as follows:

1. Reduction in harmonic residual currents in normal operation, due to the high value of earth coil reactance.
2. Reduction of earth current in case of a fault.

Two of the principle disadvantages of the earth coil system from the standpoint of interference are:

1. The increase in fundamental frequency residual current, due to dissymmetry in line or load.
2. Under abnormal conditions the increase in residual voltage.

This latter point is of particular importance on inter-connected systems because with the earth coil system there is no adequate system of relay protection for isolating a faulty feeder. It would be necessary, therefore, to "hand pick" the lines to isolate the faulty feeder, and during this time the large residual voltage

might produce noise interference. If such a condition arises the change from a grounded neutral to an earth coil system would change the type of interference trouble from that due to high induced voltage at fundamental frequency existing momentarily to that of noise interference lasting a much greater length of time.

More important, however, than the considerations discussed above is the general question of the desirability of the earth coil from the standpoint of the power system. If the earth coil produces troubles similar to arcing grounds or produces excessive potentials, then failure of power apparatus will follow. Hence, the application of the earth coil as an interference remedial measure is dependent, primarily, upon its satisfactory operation from the viewpoint of the power system.

The most significant fact in connection with the discussion of the merits and limitations of the earth coil system is the fact that all the power men who have expressed themselves in the discussion are in agreement on the point that the Petersen Earth Coil System is not of general application. Mr. Lewis stated that the field of the reactor at the present time would seem to be limited to moderate voltage and moderate length systems. Mr. Hanker stated that it appears that the earth coil is not suitable for general application on power systems, and that the most suitable condition for the application of the earth coil is on moderate voltage systems of rather limited extent. Mr. Warren has stated that the Petersen coil (as an interference measure) cannot be used under conditions where it is incompatible with the service requirements of the power company.

R. N. Conwell: Realizing that the Petersen Earth Coil may be considered from two points of view, the authors preferred, in this paper, to consider the device only in the field which it was originally designed to fulfill, *i. e.*, as an arc suppressing device, for the suitability of the device as a remedial measure in cases of inductive interference must depend upon its acceptability and proper functioning as a suppressor. The tests were designed to show the suitability of the device both as an arc suppressor and as a remedial device for interference to signal lines. The effect of the Petersen Earth Coil on adjacent signal lines, based on these tests, has been covered in the report of the Inductive Interference Committee, N. E. L. A. and presented at the Forty-fifth Convention, Atlantic City, N. J. May 15-19, 1922. As a result of the information obtained, both with regard to the operation of the coil on the power system and its effect on adjacent lines, it was decided that the device was not suitable for the purpose for which it was recommended.

Mr. Ferris refers to an extensive installation of the Petersen system in Switzerland and states that "the coils in this case have air cores, whereas in all other cases they have iron cores." I have been advised that some of the coils on this system also have iron cores, installed to limit the overpotentials as explained by Mr. Evans.

Some difficulty has been experienced through over-potentials in those sections equipped with air core coils, which resulted ultimately, in the failure of transformers.

It is noticable that all of the power engineers taking part in the discussion, emphasize the advantages of the solidly grounded system and since the Petersen Coil System approaches the ungrounded system in characteristics, the use of such a device appears to be a step backward.

AN ANALYTICAL INVESTIGATION OF THE CAUSES OF FLASHING OF SYNCHRONOUS CONVERTERS*

(Shand) New York, N. Y., February 16, 1922

J. L. Burnham: I would like to discuss the paper in the reverse order from which it is given. To show the relation of Mr. Shand's paper to previous discussions on this subject, a brief review of the bibliography he has appended seems desirable. In 1910 Messrs. Lamme and Newbury presented a paper on the use of commutating poles in synchronous converters in which they implied doubt of their usefulness. Their reasons, broadly stated, were:

Pulsation in the armature reaction and disturbances of the normal relation between alternating and direct current with quick changes in load, which caused wide variations in the resultant commutating field excitation for a given load. The phenomena discussed in Mr. Shand's paper were qualitatively stated at that time and since have been enlarged upon by others. Mr. Shand now gives a more definite picture of what occurs during sudden changes in load and short circuits.

In the discussion of Messrs. Lamme and Newbury's paper I gave results of tests on 25-cycle, 1200-volt converter with a large air gap for the commutating pole which gave decided improvement in performance for heavy loads thrown on and off. Since that time it has been the practise to use large air gaps for commutating poles of 25-cycle synchronous converters. For 60-cycle railway converters the large air gap was not sufficient to give the desired performance. The effect has been increased in the development of high reluctance commutating poles.

In 1914 Mr. Yardley presented a paper on the use of reactance for protection of synchronous converters. The results obtained did not seem encouraging and reasons were presented in the discussion at that time showing the inherent difficulties that would be introduced by the use of reactance, particularly in the a-c. circuit. These reasons are further emphasized in Mr. Shand's paper.

Recognizing these inherent characteristics of converters we began work to devise means for eliminating the effects with the view of avoiding damage to the machine and minimizing interruptions to service. Two lines of investigations were followed.

First: To take care of the flash so it would not spread and would be stopped when the short circuit was removed and

Second: To prevent formation of the arc.

The first line of investigation resulted in the development of flash barriers and the second in the high speed breaker. A paper presented at the annual convention in 1918 by Messrs. Linebaugh and Burnham described the investigations and the devices then developed. At that time we made the first claim for complete protection of a converter against any disturbances in both a-c. and d-c. systems, that would give interruptions to service no longer than ordinarily resulting from moderate overloads that would trip the main circuit breaker.

In 1919 a line of high reluctance commutating pole 60-cycle railway converters was developed and also a new type of protected brush rigging was introduced to give greater clear distance between brush holders of opposite polarity. The high reluctance poles increased decidedly the amount of disturbance that the machines would stand without flashing and the new type of brush rigging gave much less opportunity for the arc to spread and do damage. These improvements made the 60-cycle railway converter much better for average service when protected with the usual devices.

The next year, 1920, Mr. M. W. Smith presented a paper on "Suggested Remedies for Flashing of 60-Cycle Converters" which reviewed some of the phenomena involved and described tests made on the so-called flash suppressor and protected brush rigging. Tests indicate that under very delicately adjusted conditions some protection would be afforded but at that time the scheme was not considered commercially useful. I assume that this is still the status of this line of investigation.

Regarding Mr. Shand's conclusions suggesting main lines of progress: No 1 is well recognized and I believe has been followed by most designing engineers for a number of years past if for no other reasons than lower costs.

2. High reluctance commutating poles were investigated about 5 years ago and a complete line of 60-cycle, 600-volt converters was developed and standardized in 1919.

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*A. I. E. E. Journal, Vol. XLI, 1922, March, p. 174.

3. Experimental work on flash barriers was done 5 to 6 years ago and results were described in a paper presented at the annual convention in 1918 and have since been used for certain difficult service, but principally for automatically controlled machines.

4. The high-speed breaker investigation started about six years ago. At that time there was no information to determine what speed would be required of a d-c. circuit breaker to prevent flashing on short circuit. I recommended that it be made to open the circuit within ½ cycle for 60 cycles or 1/120 of second, the time in which a commutator bar passes from brushes of one polarity to those of opposite polarity. This was about 20 times faster than existing breakers and seemed a most difficult problem but this speed was attained in some breakers built about 5 years ago, and a new design, much simpler, stronger and cheaper has since been built to give the same high speeds.

To give a better idea of the form of protected rigging and flash barriers, and the performance of machine under short circuit, I wish to show some pictures:

Fig. 1 shows short circuit on a 25-cycle, 1200-volt converter built in 1910. This is the machine on which experiments with

Fig. 1—Short Circuit on Type H C 6-750-500-1200 Volt Synchronous Converter

large air gaps for the commutating pole were made and which permitted 4 times load to be thrown on and off without any serious disturbance. However, when short-circuited this machine arced over between adjacent sets of brush holders, from brush holders to bearings and even to projecting field connection strips. The amount of damage to the machine was remarkably small, compared to the pyrotechnics and effect on the operators nerves.

Fig. 2 shows a more modern form of brush rigging assembled on a 500-kw., 60-cycle standard railway machine.

To show more detail of a brush holder bracket, the next picture (Fig. 3) is an end view with the insulating end cover removed. It will be seen that the rigging is completely enclosed by insulating material and that the spring is radially in line with the brush. This type of rigging covers a very narrow portion of the commutator and gives maximum clear space on the commutator over which an arc may be established. This increased the load disturbances that a machine will stand without flashing over but it is not entirely effective in preventing a flashover when short-circuited.

Fig. 4 shows flashover with this sort of rigging, the current being interrupted by a breaker of ordinary speed. Such a flash will generally clear itself, as short circuits in service are generally limited by feeder resistance, but occasionally will hang on long enough to trip the a c. circuit.

Fig. 5 is a 750-volt, 60-cycle converter having the radial type brush rigging and latest type flash barrier.

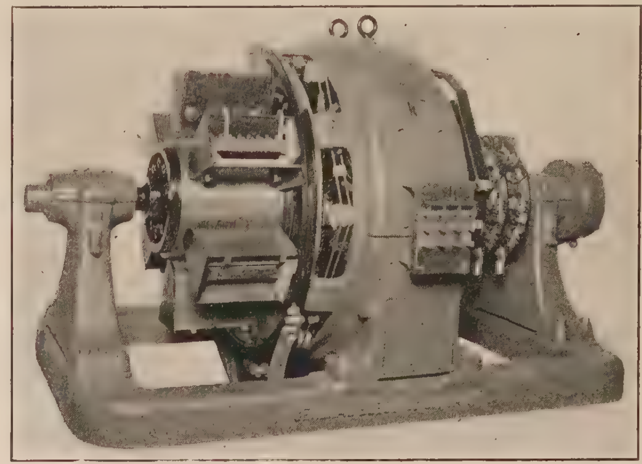

Fig. 2—Type H C C-6-500-1200-600 V C W Synchronous Converter

Fig. 6 is a perspective and cross section of the flash barrier, the action of which is explained as follows: when short circuit occurs the arc is formed between the brushes and the leaving commutator segments, being drawn out in direction of rotation as shown by the arrow and expanding outward. The arc is mechanically scooped from the commutator by the pointed barrier

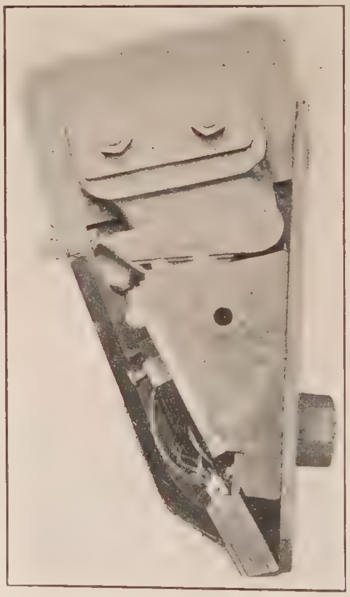

Fig. 3—Radial Brush Holder Unit Outer End Insulation Removed

which has metal inserted in its face. This metal and the barrier as a whole has a cooling effect, reducing the arc in volume and directing where it can do no harm by completing any further short-circuit paths. A second and third scoop shaped barrier are also provided as additional factors of safety in case of poor adjustment or defect of the first barrier. It is seldom

that the second barrier is ever required to move any of the arc from the commutator. The member at right angles and in front of the first barrier shown more clearly in the perspective splits the arc and confines that portion developed in the front of the two sections in their respective sections so they do not pile up at one corner, thus avoiding the escape of conducting gases under the side member. This form of barrier allows free expansion of gases, by proportioning the expansion chambers with increasing area at increasing distances from the commutator. Furthermore, it being low, releases the gases quickly after changing their course and allows free dissipation in the open air.

As has been previously shown for the radial type of protected brush rigging, it is not sufficient to have the brushes and holders surrounded with the insulating materials. It has been demonstrated that the arc, when formed must be quickly lifted from

Fig. 4

the commutator or otherwise quickly and definitely disposed of to insure against interruption to service.

Fig. 7 shows a short circuit on two 750-volt, 60-cycle converters in series for 1500 volts, protected by flash barriers and circuit breaker of ordinary speed. The current was approximately 20 times full load. The exposure of the negative was throughout the short-circuit period. It will be seen that the arc is scooped from the commutator by the first barrier and thrown out almost radially where it can do no harm. Sixty-six of these short circuits were applied in succession and no appreciable burning or damage done that would prevent the machine from carrying its usual loads. The photograph is the 46th short circuit and is representative of all. This is probably the most severe short-circuit test ever applied to a commutating machine, the current in each of the 66 tests being about 20 times full load.

Fig. 8 is a side view looking down into the barrier, showing how the arc is confined to the first expansion chamber following the brushes. It is evident how the arc splitter holds the arc from moving sidewise.

As a-c. disturbances may also cause flashing, barriers are equally useful in such emergencies.

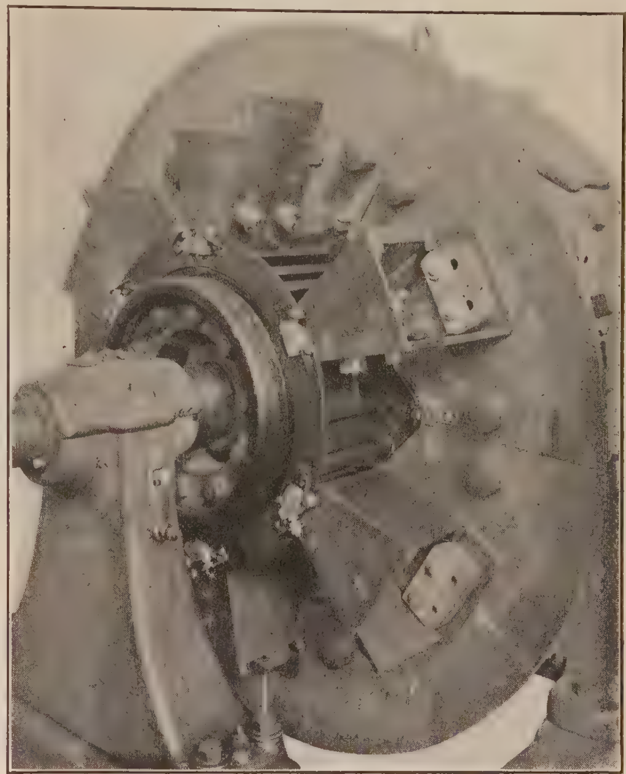

Fig. 5—Radial Unit Type Rigging with Flash Barriers, 300 Kw., 60-Cycle Synchronous Converter

Fig. 9 is a short circuit of the same machine protected with barrier and high-speed breaker, two machines being operated in series at 1500 volts. It will be noticed that the high-speed breaker has so reduced the sparking unit that it is only slightly visible.

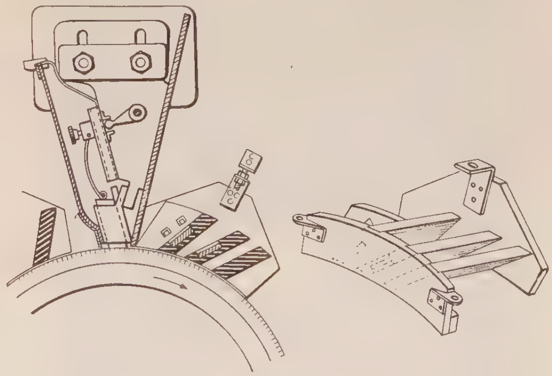

Fig. 6

Fig. 10 shows the 750-volt, 60-cycle converter with flash guard removed after it had been subjected to 50 high-speed short circuits. The commutator, brushes, and barriers were unburned. The only mark indicating that short circuits had occurred were slight soot deposits.

It will be noticed that the barriers have three point supports and may be quickly removed by unscrewing three nuts.

Fig. 7

Fig. 11 is a view of 1500-kilowatt, 600-volt, 50-cycle machine with a different type of brush rigging undergoing short circuit with barrier and high-speed breaker protection. The total amount of sparking is completely visible and will be noticed as a small triangular point of light. The barrier was not needed

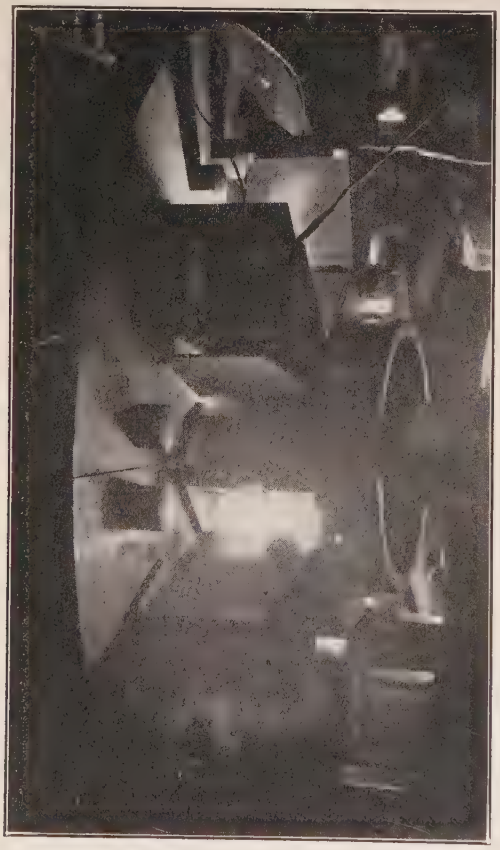

Fig. 8

for protection in this case but is presented as a good view to show the construction.

J. J. Linebaugh: The conditions existing in d-c. generators and synchronous converters under load and short-circuit conditions are radically different, due to the interconnection of the a-c. and d-c. circuits so that commutating conditions are vitally

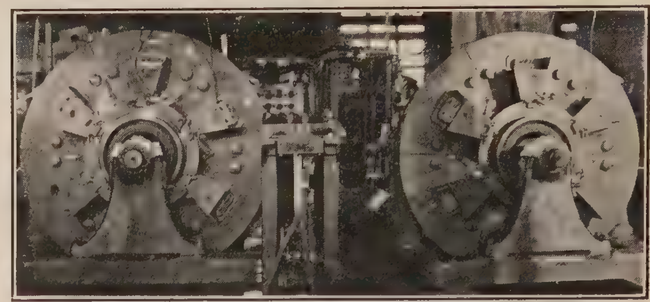

Fig. 9—Short Circuit on Two H C C 6-300-1200-750 Volts—Two Machines in Series 1500 Volts—Equipped with Flash Barriers. High Speed Breaker Set to Trip at 1400 Amperes. Machines Carrying Normal Load when Short-Circuited

affected and different remedies have to be used to produce a good commercial machine.

Figs. 9 and 10 in the paper show very clearly the reason for the flashing of a synchronous converter under rapidly decreasing load, due to opening of the circuit breaker and the great benefit obtained by the use of a high-speed circuit breaker. It is evident that the high-speed breaker removes the cause of

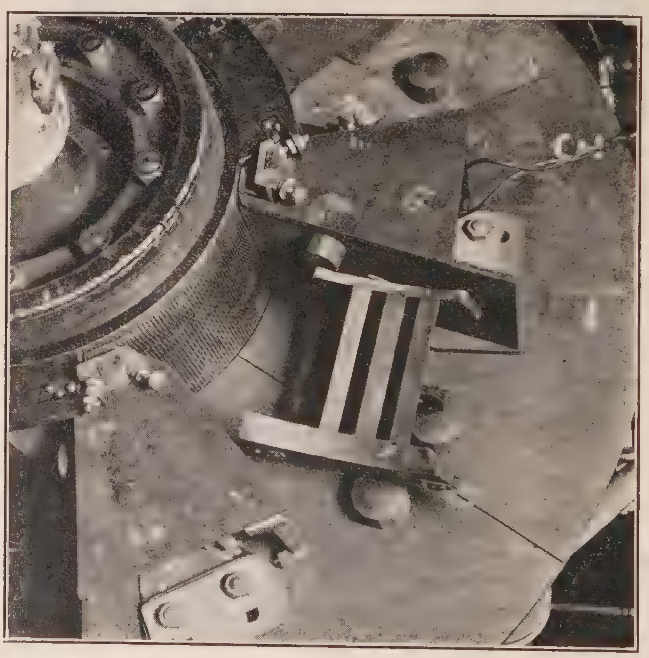

Fig. 10—Type H C C -6-300-1200-750 Volt Synchronous Converters with One Barrier Removed after 50 Short Circuits, Protected by High Speed Breaker

the high voltage generated between bars as shown in Fig. 9, due to the fact that the short circuit is prevented from reaching a high value and reduced in a very short interval of time. The resulting ampere second load is so small and of such short duration that it does not cause great enough armature displacement

to give sufficient voltage difference to hold an arc when the commutator bars move from one brush holder to the next.

The flash barriers described by Mr. Burnham are designed to take care of just such phenomena as described by Mr. Shand in Figs. 5 and 9, as the resulting arc is wiped off and raised above the commutator and cooled and dissipated so that the continued growth of the arc is suppressed. The long thin

Fig. 11

path between the barrier and commutator also tends to baffle the arc and the heat is extracted due to the cooling obtained from the barrier. If the arc should persist after the first barrier or hurdle, it has a chance to expand and the operation is repeated. Actual experience indicates that two of these hurdles are sufficient to stop practically any arcing which has been experienced. Tests indicate that a form of barrier such as described, designed to remove the arc quickly from the commutator, is superior to the narrow barrier described by Mr. Shand. These barriers are applied to all machines above 750 volts, as standard practise, in addition to automatic substation machines, and have been very successful in actual operation for several years.

The 60-cyle 750/1500-volt machines shown by Mr. Burnham, have all the improvements in design developed during the last few years and their behavior under test indicates that they are practically equal to the 25-cycle converter in every way.

Mr. Shand has not covered the effect of operating the rotary converter at poor power factor due to weak or strong shunt fields, and oscillograms similar to Figs. 5 and 9 would be of interest.

One advantage of the barrier, not brought out, is its ability to take care of flashing caused by a-c. disturbances of any kind. The high-speed breaker does not take care of this trouble, but the barrier prevents flashing over from such causes and the combination of the two types of protection as stated in the 1918 paper by Mr. Burnham and the writer, gives absolute protection under all short-circuit conditions.

E. B. Shand: The intention in writing this paper was not so much to set forth any new principles or any radical conclusions as to present the problem of converter flashing from a standpoint which has been in the past, it is felt, somewhat neglected. It has not been entirely neglected, for as Mr. Burnham has stated, most of the facts of the case have been stated at one time or another, but usually without proper correlation and seldom with any adequate experimental substantiation. The author, however, wishes to acknowledge a debt to the results of some unpublished work done by Mr. C. E. Wilson in 1910 under the direction of Mr. B. G. Lamme. This comprised tests and calculations on a converter in short circuit with reference to the inertia energy involved.

With respect to Mr. Burnham's references to the conclusions of my paper, these are not intended to be regarded as being a departure from present practise. All of the principles involved have been well recognized and to find the first developments of any one of them, it would be necessary to go back at least a decade.

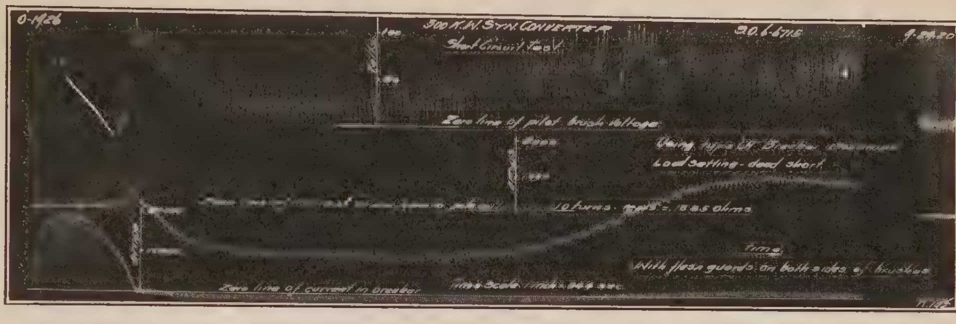

Fig. 12

The performance of the 750-volt, 60-cycle converters as shown in Fig. 7 of the paper is indeed striking. It is a demonstration of machines immune from destructive flashing under extreme, severe conditions. The result of a dead short-circuit test on the 500-kw. converter referred to in the paper is shown herewith, in Fig. 12. A circuit breaker of the ordinary type was used on this test, but the flash guards used were considerably simpler in form than those described by Mr. Burnham. The condition of the machine was, in fact, practically the same as for Fig. 9 of the paper except that it was completely short-

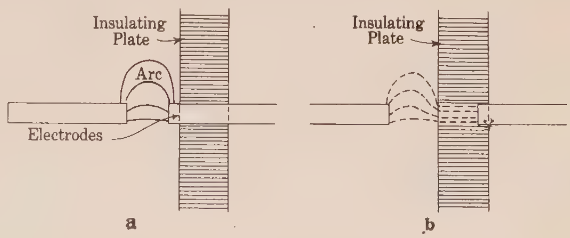

Fig. 13

Fig. 14

circuited. The current rose to 22 times its normal value, at which point a flash of limited proportions occurred. The machine dropped out of step and later dropped back a second pole into step again. Spitting occurred in both instances, as would be expected, for the condition would be the same as synchronizing with the brushes down after starting. As may be seen from the oscillogram, the flashing was never destructive, and there was no injury done to the machine beyond a slight blackening of the commutator so that there was no reason why the machine might not have been put directly back into service.

In reference to the function of flash guards, I do not thoroughly agree with their principle of operation as given by Messrs. Burnham and Linebaugh. It is stated that the flash guard accomplishes its results by scooping the flash from the commutator; this may be true to a certain extent but to a greater extent it is the effect of choking off the core of the arc which makes it unstable and breaks it. For instance, Fig. 13, take the case of an arc struck between two electrodes, one electrode projecting through a plate of insulating material. If this electrode be now withdrawn, the arc is confined at one point to the dimensions of the hole, and if this be small enough the attenuation of the arc will quickly break it. When as one of these electrodes a bar passes under a guard, the arc is attenuated in the same manner and broken. (Fig. 14).

WAVE FORM AND AMPLIFICATION OF CORONA DISCHARGE*

(Whitehead and Inouye), New York, N. Y., February 16, 1922.

J. H. Morecroft: There is only one point on which I can add anything and that is on the use of the vacuum tube as a voltage rectifier. It is an experimental instrument not used very much as yet by electrical engineers, but as Dr. Hull told us some time ago, it will be used by every engineer very soon. There are certain cases where voltages are to be measured where it is impossible to get the measurement without the use of the vacuum tube.

Sometimes we want measurements in a circuit having but a few millivolts of power, of the order of one, two, three, four or five volts, and a frequency of perhaps a million cycles per second. If you have to measure that kind of a circuit with the ordinary engineering apparatus, you throw up your hands and say it is impossible to do it, there is no indicating instrument which will respond, even if it used up all the millivolts there are in the circuit, and if it did respond, you would not know what the reading meant, because the errors at a million cycles would be excessive, and it would be necessary for you to have recourse to the newer devices, of which the vacuum tube is the most important.

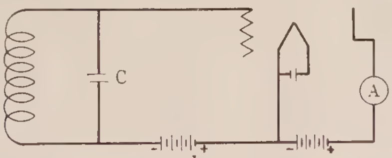

Fig. 1—Scheme for Measuring Maximum Voltage Across Condenser C

Take an oscillating circuit with an unknown voltage across the condenser, and a frequency of, let us say, a million cycles. and measure the voltage. We might try to put a voltmeter across the condenser. If we did, the voltmeter would short-circuit the current, and we would have no voltage at all, so that evidently will not work. A scheme like this, however, will work. Put the grid of a vacuum tube as in Fig. 1, insert a biasing battery which makes the grid of the vacuum tube negative, and if the grid of the vacuum tube is made sufficiently negative, there will be no current going through the plate circuit. When this circuit is not excited, put on sufficient negative voltage, on the grid by means of the biasing battery so that the plate current is cut off, and then, if you start to excite the circuit, the grid will go up and down in potential, and as soon as it goes positive, a little bit more than the critical amount, as previously adjusted, then the grid, going positive, will allow a little bit of current to go through the plate circuit, and if the plate circuit instrument is sensitive enough, you can read it. The biasing battery must now have its voltage increased to reduce the plate current again to zero; the amount of increase in biasing voltage is the maximum value of the high-frequency voltage across *C*. In the case of corona you ordinarily have much more power available than in the high-frequency oscillating circuits used in radio.

In looking over the curves, I notice that Dr. Whitehead gives the curve for a certain type of Western electric tube in Fig. 13, and uses the diagram shown in Fig. 14. If that is so, there is an error in the curve, an error due to the 1.5 meghoms, which is connected in the circuit. If in taking a curve we make the grid at all positive, of course the grid will draw current, and this current will have to flow through the 1.5 megohm resistance, and the drop in this resistance will be very high compared to

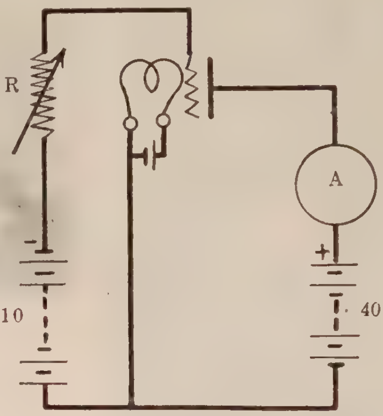

Fig. 2

the voltage being used. For example, if we have two micro-amperes flowing in the grid circuit, which is a pretty small current, if the two micro-amperes go through 1.5 megohms, there is a drop of 3 volts in the resistance. If we have 4 volts in the grid battery, the grid will be positive only to the extent of one volt. It looks to me as if something of that kind may have taken place, because it is very seldom in the Western Electric tubes of that type that the plate current falls away so rapidly, and becomes horizontal, as indicated in Fig. 13.

G. D. Robinson: I would like to call to Dr. Whitehead's attention a circuit differing somewhat from the one that he has shown.

In the corona voltmeter we are interested in an extremely small flow of current through the more or less ionized gas between electrodes in the meter. When the gas between the electrodes is normal the resistance between them is substantially infinite, but at the moment that corona starts appreciable ionization occurs and this resistance drops to a lower, but still enormous, value. As the current which can be passed through this ionized gas is insufficient to give a deflection on a portable meter, it has become desirable to cause this small current to control a larger current which can operate the portable meter. Dr. Whitehead's circuit uses the *I R* drop caused by the flow of this small current through a resistance unit to control the grid voltage and plate current of a three element vacuum tube. The variation of this circuit which I have in mind makes use of the *I R* drop *through the tube itself*, from filament to grid, to produce a similar result. The circuit will be as shown in Fig. 2. Here *R* represents the variable resistance of the ionized gas path between electrodes. *A* is a sensitive portable meter, perhaps one giving full scale deflection with one milliampere. I have found it desirable in a similar case to use more voltage in the grid circuit than in the plate circuit. The figures beside the batteries are possible values for these voltages.

In considering the effects of the grid upon currents in a circuit such as this it is customary to use curves showing the value of

*A. I. E. E. Journal, Vol. XLI, 1922, January, p. 1.

plate current and of grid current for various values of grid voltage. With negative grid voltages the grid current is so small that frequently it is neglected, but this current is *not* zero and in this case it is *not* negligible. When these characteristic curves have been taken with a sufficiently sensitive galvanometer it will be seen that any attempt to increase the negative grid current beyond a certain very small value will result in shutting off the plate current completely. This "very small value" will vary greatly with different tubes and different adjustments of plate and filament voltages. It is at least as small as 10^{-8} amperes in some tubes. Yesterday I obtained from Mr. Chubb of the W. E. & M. Co. the opinion that by removing the base, a three-element vacuum tube might be obtained in which a current of 10^{-12} amperes in the grid circuit would be enough to shut off the plate current. What does this mean? It means that if the ionized gas path in the corona voltmeter permits the passage of the *very small value* of current a change of current of the order of one milliampere can be obtained in the portable meter when corona starts.

This circuit does not satisfy the condition that the meter should read zero before corona starts, but obviously the meter could be shunted by a battery and resistance so that it would satisfy this condition. In the circuit shown in the figure the meter reading should be substantially constant at a large value before corona starts. At the start of corona the reading should *drop sharply*. I am of the opinion that this circuit can be made to give greater current amplification than was obtained by Dr. Whitehead.

As a-c. voltages applied to the grid of the vacuum tube will affect the reading of the d-c. meter in the plate circuit, precautions to reduce any such a-c. voltages to a small value would probably be required with this circuit.

John B. Whitehead: I wish to thank Professor Morecroft and Mr. Robinson for their suggestions in connection with the tube circuits. After a lapse of six months I can recall nothing which suggests that the connections in Fig. 14 were not used as there found. However, I understand that Professor Morecroft's comment refers particularly to the upper portion of the curve of Fig. 13, where the grid voltage becomes positive. The critical condition in which we are interested is that of zero value of the plate current when the grid has a considerable negative potential. It is quite possible, as Professor Morecroft suggests, that there may be some current in the grid circuit. If this is the case, the presence of the grid leak would undoubtedly cause the value of the grid voltage to be other than that indicated. The absence of the grid leak in Fig. 15 would therefore cause a change in condition. However, it will be noticed from Table 2 that observations were taken at various values of grid voltage, showing that the most effective were between 7.4 and 8.8.

As to Mr. Robinson's comment, I judge that he suggests that the indicating galvanometer shall carry current before corona forms, and fall to zero after corona forms, this result being accomplished by varying the current in the grid circuit. It is possible that a greater sensitivity may be obtained thereby, but I question whether the conditions will be as practicable and uniform as those well-known connections that we have used. Moreover, there is a considerable advantage in having the instrument stand permanently at zero, with deflection for the critical condition rather than the reverse. I hope that Mr. Robinson will have an opportunity to try the connection he suggests.

PREVENTION OF TRANSIENT VOLTAGE IN WINDINGS*

(WEED), NEW YORK, N. Y., FEBRUARY 16, 1922.

M. E. Skinner: I do not understand from the paper that actual transformers or even reactors have been constructed in which the inherent but rather disturbing effects of leads, connections and taps, space occupied by the conductors themselves, and of non-uniform inductance per turn, have been overcome. The paper appears to crystallize several ideas as to how these inherent difficulties may be overcome, but the structures illustrated are still a long way from anything employed at the present time in power or distribution transformer construction. It is interesting to note that the solution chosen for the problem of taps is their complete elimination. This is undoubtedly the most effective as well as the easiest way out. The fact that it has been found advisable to reinforce the insulation of the end turns of so simple a winding as that employed in an air core reactor, illustrates the difficulty of applying the principle upon which Mr. Weed's paper is based to commercial apparatus.

In this connection I should like to point out that the number of transformers which fail from overheating and from mechanical stresses is probably as great as the number which fail from voltage stresses. Of the insulation failures, relatively few occur between line turns. It would therefore appear as though the present practise of padding the insulation between the turns connected to the line was taking care of the situation admirably and this with no decrease in mechanical or thermal reliability and at very little increase in cost.

The picture drawn by Mr. Weed of the ease with which high voltages are built up in a transformer winding is rather alarming. However, it is comforting to remember that actual exhibitions of these high voltages on commercial systems are rare.

I believe that more improvement in service records will result from a reduction in the number of taps and leads, and from more thorough insulation of these exposed points in transformer windings than from such a delicately balanced winding construction as is proposed in this paper.

F. F. Brand: Mr. Weed is to be congratulated on the clear manner in which he has outlined the theory of transient voltages in windings and methods of eliminating them in simple cases.

There are unfortunately other factors than insulation to be considered in transformer design. Some of these fundamentally tend to have an opposite effect on the design.

Consider only the mechanical forces between windings. These are naturally higher in low-voltage transformers than in those for high voltages. The smaller insulating clearances necessary, the better space factor of the windings, result in increased flux densities surrounding the windings and thus result in higher forces.

For this reason the style of winding most suitable for low voltages may be radically different from that suitable for high voltages. In the former, mechanical force problems may predominate, in the latter, insulation problems.

Thus any method which makes it easier to insulate between the various parts of the structure, which enables the windings to be made more compact, increases the mechanical forces, and this must be considered in selecting the type of winding.

There is also a limit, due to variation in insulating value of the materials used, or to possible damage of the insulation, beyond which it is not safe to reduce the insulation and this, in connection with the mechanical forces produced under such conditions as short circuits, may make it uneconomical or impractical to use windings of the types illustrated which can be perfectly shielded.

Most of our present transmission systems are very complicated, there are wide variations in transformer requirements even on one system or circuit and these militate against the use of such shielding arrangement.

With the growth of extra high-voltage systems, where synchronous regulation becomes necessary, where systems assume the type of great trunk lines, the transformer requirement should become more fixed under all operating conditions. Furthermore the tendency to use solidly grounded neutral enables radical departure in transformer design to be made. These facts may and should allow the use of more perfect shielding of windings than has yet been accomplished commercially,

*A. I. E. E. JOURNAL, Vol. XLI, 1922, January, p. 14.

although we must recognize that the grounded neutral system will probably increase the frequency of short circuits, because every insulator failure at once develops into a short circuit, and thus mechanical conditions may again be of increased importance even in extra high-voltage designs.

H. O. Stephens: In considering the design of transformers to withstand the transient voltages which always occur in operation the designing engineer has the choice of four methods.

1. He may disregard all means of eliminating or reducing these excess voltages and must recognize that they will be present between turns, between coils, between windings and between windings and ground. In this case it will be necessary to provide sufficient insulation at all of these points to withstand the maximum transient voltages that may occur under the most severe operating conditions.

2. He may use lightning arresters at all points of danger to prevent rises in voltage materially above the line voltage. He may use high-frequency absorbers to prevent line oscillations below the discharge voltage of the arresters. He may shunt inductances with resistors where possible in order further to absorb the energy in high-frequency oscillations. If the expedients employed to keep the abnormal transient voltages as low as possible are wholly successful, he may insulate the transformer between adjacent parts to withstand only the normal voltages with a reasonable factor of safety.

3. He may design the transformer along the lines brought out by Mr. Weed's paper so that the relation between inductances and capacitances within the transformer are such that a uniform distribution of transient voltages throughout the windings will be obtained. In this case he may also provide the transformer with only the necessary insulation to withstand the normal voltages with a reasonable factor of safety.

4. He may choose a proper balance between all of the three methods outlined above, using lightning arresters and whatever means are available for reducing the transient voltages to a minimum, designing the transformer so as to obtain as uniform a distribution of voltages throughout the windings as practicable and finally providing sufficient insulation to withstand the voltages which calculation and experience show will be developed between the adjacent parts of the windings.

Transformer design consists so largely in choosing a proper balance between diametrically opposing characteristics that it is seldom possible to carry out any single idea to its logical conclusion. If it were always possible to design transformers with the simple types of windings shown in Mr. Weed's paper it would be feasible to carry out the shielded winding construction to its full possibilities. Unfortunately however, the transformer is the connecting link in all systems between all other electrical apparatus and must therefore be adapted to all of the peculiarities and vagaries of all apparatus and systems. Even in the simplest design taps are usually necessary to compensate for variation in system conditions and a very large percentage of transformers have to be designed to operate on different parts of the same system and in some cases on different systems so that they may and very frequently do become extremely complicated. As soon as taps or series multiple connections are a necessary feature of the windings it becomes practically impossible to carry out a system of shielding the windings which will give anything like a uniform distribution of transient voltages.

In the present state of the art it would appear that the best engineering judgment would dictate that we follow the middle ground outlined under paragraph four. Experience has shown that with proper consideration given to system layout and operation, with careful disposition of the transformer windings so as to avoid groupings that will actually invite dangerous resonant conditions, and with reliable insulations so disposed as to insure ample protection against these now well-understood transient voltages, modern high-voltage transformers have proved very reliable from an insulation standpoint.

However, Mr. Weed deserves much credit for the way he has worked up this physical conception of the behavior of transients and even if it may never prove entirely practical to adopt it in its entirety, there is no doubt that consideration of this method of preventing dangerous rises in voltage has already been of considerable benefit to the transformer designer in teaching him how to avoid specially objectionable combinations of internal inductance and capacitance.

L. F. Blume: The value of Mr. Weed's paper consists in its emphasis of the fundamental principles which govern the relation between inductance and capacitance of a winding. A transformer winding, reactor or similar electrical apparatus, usually classed as possessing the property of concentrated inductance is in reality a very complex circuit consisting of a large number of inductances and capacitances in series and in parallel. For example, a typical transformer winding possesses capacitances from turn to turn, from layer to layer, from coil to coil and also from the external surfaces to other parts of the apparatus and to ground. These capacitances are so enmeshed with each other and with the various inductances of which the winding is composed that it is generally hopeless to disentangle them for purposes of analysis.

However by clearly describing an ideal principle of design Mr. Weed makes a forward step towards the understanding of the problem, and, what was heretofore a hopelessly complex mesh-work now becomes a regular pattern of inductances and capacitances the action of which is readily understood.

The principle may be crudely stated as follows:

Imagine that the conductors in a winding are broken at each turn so that no current can flow through the copper. Under this condition the voltage distribution within the windings due to an alternating source of potential is entirely governed by the capacitances possessed by the windings.

If the winding has been designed so that the voltage distribution throughout the winding under the aforementioned condition is identical with the voltage distribution under ordinary conditions, then there can never be an interchange of current between the inductance and capacitance portions of the winding and therefore under all conditions of excitation, normal and abnormal, the voltage distribution remains unchanged.

Several transformer windings built in Pittsfield in accordance with this principle were subjected to all sorts of high-frequency tests and voltage impulses. A complete verification of its theory was obtained. In attempting to apply this principle, however the designer cannot lose sight of other very practical considerations. Mechanical strength, cost of winding, reactance, cooling and insulation, all require due thought and at best a design is a compromise in order that all of these may be properly taken care of. The elimination of internal concentrations or their reduction to a minimum is one of these, and the designer has the choice of reducing the abnormal stress by skillful manipulation of the capacitances or of employing sufficient insulation to withstand them.

The various shielded windings which are described by Mr. Weed differ from ordinary windings used in transformers mainly in two respects. First, a metal shield is connected to each terminal. Second, capacitance of the winding to ground is eliminated.

From these differences it is a simple step to the conclusion that voltage concentration and internal resonance in ordinary windings is largely due to the small surface area of the winding terminals, and to the comparatively large capacitance of the coil surface to other parts and to ground; and by increasing the one and decreasing the other improvement in coil design from the standpoint of transient voltages might be expected.

Appreciable improvements can thus be secured in many trans-

former windings without employing the rather radical departures that are suggested by Mr. Weed, and without sacrificing other important considerations. For example the use of a metal clamping plate in close proximity to the end coils and electrically connected to the terminals in a cylindrical coil structure very effectively reduces the voltage concentration on the end turns when a surge occurs. Again by shortening the coil stack the surface capacitance to ground is decreased and by this means voltage concentration under abnormal conditions is appreciably lessened.

Whether it is desirable to proceed further toward the ideal winding depends in addition to the limitations imposed by other design considerations mentioned above, upon whether the abnormal voltages introduced are sufficiently severe or occur sufficiently often, and whether the use of more insulation may not serve just as well.

Abnormal voltage stresses due to any cause whatever occurs at most, only occasionally and then the duration is extremely brief. This, together with the fact that a given insulation is capable of withstanding for very short time a much greater stress than for longer periods, helps to reduce materially the burden on the insulation.

The above facts are presented not for the purpose of discounting in any way the value of Mr. Weed's paper, but to point out that failure of applying to practise entirely the principle in the manner described by him is due not to a lack of appreciation of the importance of the theory but to many other factors that help to determine the nature of the design.

C. L. Fortescue: This paper is very interesting to me for many reasons. One of them is that I recognize the same ideas that have been used in connection with obtaining better distribution on strings of insulators. It seems rather peculiar that transformer windings and strings of insulators should require similar methods in order to get good distribution under transient conditions, but such is the case. If you could imagine a uniform inductance which has no distributed capacity, that inductance under an impulse would divide the impulse equally throughout all parts of its windings. However, it is impossible to get an inductance without distributed capacity, and therefore we must consider what determines the distribution of the impulse through a winding which has distributed capacity.

First of all, leave out of account the inductance itself. If we have capacity, in order to determine the potential of that capacity, we must have charge. That means we must have current flowing for a finite time. The impulse of voltage across the inductance is determined by the rate of change of the impulse, and therefore we cannot pass sufficient current in a given time to charge up the connected capacity to the right potential. In order to get the proper distribution, we must take the capacity part of our system, and so design it as to give uniform distribution of voltage.

In Fig. 3, of Mr. Weed's paper we have one method which is prosposed. That method is identical with that known in insulator strings as grading the insulators, that is to say, the insulator in the line which has a greater part of the capacity current, due to distributed capacity to take care of, is made of larger capacity—its capacity admittance is increased, and as the insulators approach towards ground, the capacity is graded,—those near the ground end being of less capacity than those near the line end. This method has been found quite effective, in giving proper distribution, and of course the distribution is entirely independent of the frequency or the rate of change.

Fig. 4 corresponds to the use of shields, such as the distribution shield at the terminal of the insulator string on the high-voltage side. This shield increases the capacity of the lower insulators, the line insulators, to the line, and grades the capacity in a manner similar to that shown by Mr. Weed; that is to say the capacity to the line is of such a magnitude that it completely annuls the distortion due to capacity to ground or the distributed capacity of the insulator string.

Fig. 5 shows another method that is being considered in connection with improving the distribution of potential over strings in insulators, that is to say, by making the capacity between adjacent insulators large compared with the capacity of the hardware to ground so that the latter becomes negligible as compared to the capacity between insulators. In this way a very excellent string distribution can be obtained.

Fig. 6 illustrates another method of shielding. For example, in the case of a string of insulators, if we put on the top and bottom of the insulators, a shield sufficiently large to give a field in the neighborhood of the string corresponding to that between two infinite parallel planes, we shall have a condition such that each insulator will have a capacity to the ground shield and a capacity to the high-potential shield of such value as to maintain each at its proper potential, and we shall get a string distribution, determined simply by the capacity between adjacent insulators.

Nine years ago I called attention of the Institute in a paper to a general theorem of electrostatics on systems of conductors having potentials, which covers in a general way the principles for obtaining any desired potential distribution. It may be stated in the following way: Arrange the system so that its natural potential distribution shall correspond to the natural electric distribution due to end electrodes or terminals. If you do this, you will get a condition in which there is no discharge between the individual members and the external space and you will then have the most efficient system.

As far as the application of these ideas to tranformers is concerned, I think certain types of winding tend towards the elimination of these transient maldistributions. The tendency is to use a distributed form of winding in which the high-tension part of the winding is removed from the ground as far as possible, and therefore its capacity to ground is decreased while of course, its capacity towards the high-tension terminals is correspondingly increased. The capacity is large for such a type of winding and it has a great deal of strength against transients coming in on the line. It approximates very closely the characteristics Mr. Weed pointed out.

J. F. Peters: When one considers the enormous voltages that theoretical considerations indicate have been produced in transformers which have been operating on comparatively high-voltage systems in the past, one wonders why any of them continue to live through the service; yet transformer failures have been comparatively rare. In more recent years the neutral of most high- and moderately high-voltage systems have been grounded either directly or through resistance, thus eliminating or greatly reducing the possibility of arcing grounds—the principal cause of high-voltage disturbances. In recent years the few insulation failures in transformers to my knowledge were not in or near the end coils and were all in ungrounded-neutral delta-connected banks.

That does not prove that comparatively high voltages may not appear across the end turns of transformers, but it does indicate that the present practise in insulation is adequate for the service, and it is accomplished with reasonable cost.

The paper presented by Mr. Weed is very interesting indeed. It shows theoretically how the maximum voltages in transformers can be reduced, but to actually approach even approximately the theoretical "constitutional remedy" outlined in the paper would be extremely difficult and very expensive. The schemes discussed by the author in connection with Figs. 8, 9 and 10 are, I believe, not as simple as one may be led to believe. With the arrangements shown in these figures it is assumed, I believe, that the total inductance of each turn is the same as that of every other turn throughout the winding. That, however, is not the case. The current that flows through the winding, due to an abruptly applied voltage, appears as a magnetizing current and a uniform current throughout the winding will not produce a uniform voltage.

This is because the magnetic circuit is not symmetrical with respect to all turns. This condition can best be seen by considering a number of identical coils located side by side and all connected in parallel. When an a-c. voltage is applied to these coils the outer or end coils will take very much greater current than the inner ones and the difference between currents of outer and inner coils will be greater the higher the applied frequency. That is, the more abrupt the applied voltage the greater will be the unequal division of current. Therefore, in order to get a uniform voltage across all turns of the structures, shown in Figs. 8, 9 and 10, the rate of change in current in the end turns of all layers must be much greater than that for the inner turns. In order to produce the proper current in all turns during the initial adjustment, the coils would have to be curved in cross section instead of straight, as indicated, which would be difficult to carry out in practise.

The schemes shown by Figs. 3, 4, and 5 and particularly that shown by 5, could be incorporated in any transformers, but it is very probable that after bringing out the additional leads and adding the cost of condensers, that the resulting transformer would be more expensive and less reliable than those built according to present practise, which are proving themselves entirely adequate.

F. W. Peek, Jr.: It was my good fortune to witness the tests and to take part to some extent in the work of which the shield described by Mr. Weed is one of the practical applications. In that investigation, made at Pittsfield, in about 1912, various types of transformers were taken and subjected to disturbances corresponding to those produced by arcing grounds. Taps were brought out from the different coils and the voltage distribution throughout the winding was measured by sphere gaps. Very high voltages may be produced in any part of the winding by varying the frequency of the disturbance.

It is surprising that a static shield can be effective in eliminating these very high local transient voltages. Yet that such is the case has been demonstrated by tests. The ideal shield described in the paper is difficult to apply in practise. However, it is approximated in practise in the way of clamping rings and considerable advantage is gained thereby.

It may be of interest to point out here that the operation of the shield is very similar to the stress distributing ring now used on high-voltage line insulators. There is this difference, how-

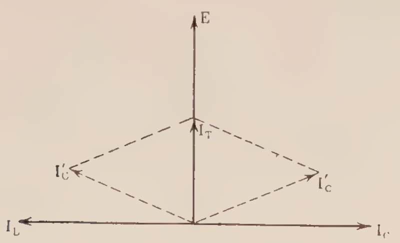

FIG. 1—FOUR COILS OF A TRANSFORMER CONNECTED IN SERIES
Letter C indicates the capacity of the coil, L the inductance of the coil and K denominates the coil. T_1 and T_2 are the terminals.

ever, in a transformer the voltage distribution under normal conditions is determined by the windings. The ring functions only under abnormal conditions. In the insulator the shield determines the normal distribution as well as the abnormal distribution.

P. Trombetta (communicated after adjournment): I find it very difficult to understand how the author got his conclusions, I find also that the paper contains some very specific contradictions which if taken seriously will upset either all his reasoning, his conclusions or both. Under the topic, "Object of the Paper," he states that it has long been known that the high voltage resulting at the terminal coils of transformer windings is due to the presence of capacitance and that it is obviously impossible to eliminate capacitance and that the subject was not sufficiently well understood to avoid the evil effects. On the other hand, farther on he proposes to eliminate these evil effects by introducing more capacitance. It seems quite clear to the writer that if the complete elimination of the capacitance would clear the effects certainly the nearer we get to the complete elimination the better should be the results and therefore it is impossible to see how by adding more capacitance we cure the effects.

A closer study of the phenomenon will, however, show that the burning of terminal coils in transformers is due to a phenomenon which is not at all mentioned in Mr. Weed's paper and which may be explained as follows:

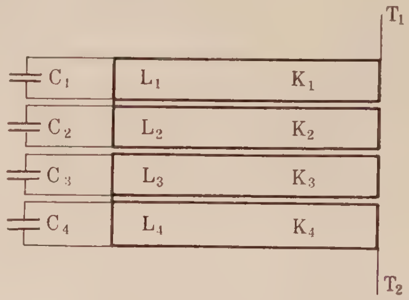

FIG. 2—VECTOR DIAGRAM OF A CIRCUIT, CONTAINING CAPACITY AND INDUCTANCE IN PARALLEL
I_C and I_L represent the currents in the condenser and inductance respectively. I_T represents the vector sum of the two currents in phase with the e. m. f.; I_C and I_L represent the current vector of such a circuti when it is in resonance and neither the condenser nor the inductance have any resistance. I_C' and I_L' represent the same vector in case the condenser and inductance have resistances.

In Fig. 1, K_1, K_2, K_3, K_4 represent four coils of a transformer; L_1, L_2, L_3, L_4 represent the inductance of the respective coils, C_1, C_2, C_3, C_4 represent the capacity between turns of the respective coils. Now as shown by Dr. Steinmetz, any system which contains distributed capacity and inductance has no fixed period of oscillation and any piece of such system may oscillate by itself irrespective of the rest of the system, so if we apply a voltage at the terminals T_1, T_2 of this transformer, we may have the transformer as a whole oscillating or any one of the coils may oscillate by itself or in combination with any number of the rest of them. Now it is well known that if an oscillating system is made up of a capacity connected in parallel with an inductance with very low resistance, at the resonance frequency we obtain the effect known as "Effet de Bouchon," which means that the circuit in which the oscillations are taking place is stopped up and no current can pass through it. The vector diagram for such a circuit is shown in Fig. 2 in which E is the applied e. m .f., I_c the current flowing in the condenser circuit, and I_L the current flowing in the inductance circuit. It is shown in this diagram that if the resistance is zero we may get enormous currents flowing through the condenser and the inductance while no current can flow through the main circuit. Therefore, if we say coil K_1 in Fig. 1 is set in oscillation at resonance and no current can flow through the circuit, the voltage drop through all the rest of the coils would be zero and the total voltage applied to K_1 is equal to the total voltage of the line. In other words, in this case of the four coil transformer, the voltage applied to K_1 would be four times its normal voltage and hence the insulation is broken down which results in the burning of the transformer.

The conditions for the above effects are more favorable the smaller the capacity C_1 and the larger the inductance L_1 of the coil because in order to start the oscillation some current actually has to pass through all of the coils and the value of initial current depends upon the capacity C, that is, by increasing C the amount

of current which must pass through the whole transformer before the system can be set in oscillation is increased on account of the fact that by increasing C the frequency of oscillations is decreased. On the other hand, it is impossible to pass within a very short time any appreciable current through the whole transformer due to its inductance and therefore by making C large enough we can prevent oscillations altogether.

J. Murray Weed: My chief effort in this paper was to give a clear conception of the causes of transient voltages and voltage oscillations in windings, with a theoretical solution of the problem of preventing them. I fully realized the difficulties involved in making general application of this solution, and the imposibility of making any application perfect, but I felt that it was not necessary to emphasize these phases of the subject. The danger is not that we will go too far in our efforts to make these applications, but rather that conservatism will unduly restrict our efforts in this direction. I feel that a thorough knowledge of the fundamental principles should enable us to make partial applications which will result in better transformers, or in transformers of equal value at less cost.

This is being done at the present time in the consideration given to the effects of various winding arrangements upon the distribution of capacitance, and in the use of metal clamping plates which are connected to the outgoing leads.

In the figures of the paper, I have suggested several methods of making approximations to the ideal arrangement, some of which may be found useful for practical application in suitable cases. I did not expect that any of the methods suggested would find general application, but I have gone as far as I have been able to go in pointing the way, and I would not be surprised to see the application of the general method here illustrated carried much further than seems to be expected by most of those who have discussed the paper.

Two or three points in the discussion require specific consideration.

In Mr. Blume's statement of the points wherein the shielded windings which I have described differ from ordinary windings, he has omitted one of prime importance. This point is brought out in the paper, but I take this occasion to emphasize it. To meet completely the conditions for uniform voltage distribution, each turn must be so positioned within the dielectric of the condenser that the potential which would be imparted to it by the electrostatic field, assuming that this field is not disturbed by the presence of the inductance is that which gives a uniform voltage distribution with respect to the inductance.

Mr. Peters has recognized a condition which no one can appreciate more keenly than I. It is practically impossible to perfectly meet the condition specified in the preceding paragraph, which constitutes the essence of the "Constitutional Remedy." The discrepancy due to variations in the inductances of different turns in a transformer winding, however, is not so serious as Mr. Peters seems to think. I presume that the results he speaks of were obtained with coils which were not linked with an iron core. That the inductances of all turns in a transformer winding are practically equal is demonstrated by the fact that transformer design is based upon this principle, primary and secondary voltages being proportional to the respective number of turns. There is, however, a tendency in the direction which Mr. Peters has spoken of, especially for high voltage windings, which are distant from the core. That I do not consider a moderate discrepancy of this sort serious is sufficiently indicated by my proposal, in the last paragraph of the paper, of the arrangement shown in Fig. 10. My conception of the effects of such discrepancies or failures to meet perfectly the conditions for uniform voltage distribution is given in the paper under the heading "Limitations of Supplemental Methods."

As for Mr. Trombetta, I feel that he may obtain a better understanding of the paper if he reads it again, together with the discussion which has been contributed by the others. His coil K_1, of course, is a part of the winding, and cannot act alone in the manner which he has described. Whatever its action, it comes within the scope of the theory which I have set forth.

HEATING OF RAILWAY MOTORS IN SERVICE AND ON TEST-FLOOR RUNS*

(Luke), New York, N. Y., February 17, 1922

M. R. Hanna: Mr. Luke has shown the difficulty of calculating accurately the temperature of the various parts of a motor when operating on an intermittent duty cycle. However I would like to point out that it is possible to obtain quite satisfactory results without any great difficulty by considering larger sections of the motor. In the case of inclosed or slightly ventilated motors we can consider the motor as a whole and in the case of well-ventilated motors we may consider the armature as a whole and each of the field windings as separate units.

After we have calculated the losses in the motor under the various conditions of load, then if we know the watts that the motor or its various parts will dissipate at any given temperature rise and the watt-hours that it absorbs in attaining this temperature rise we can, by a simple calculation, obtain the temperature rise at the various points of the duty cycle. The ratio of these two quantities, the watts dissipated and the watt-hours absorbed is practically constant for any particular motor or part of motor under any given conditions of ventilation. This ratio definitely fixes the rate of heating or cooling. By rate I mean the time required to reach a given percentage of the ultimate temperature change. The relation is the simple logarithmic equation with which we are so familiar in its application to the rise of current in an inductive circuit. The first of these factors, the watts dissipated, can be determined from continuous heat runs such as would be made to determine the continuous rating. The second factor, the watt-hours absorbed for a given rise could be obtained by calculation from heat runs such as Mr. Luke suggests as a measure of the thermal capacity or may be calculated from the weight of material. If we are considering the motor as a whole it is surprising how good a value for the thermal capacity can be obtained simply from the weight of the bare motor. To illustrate this point I have taken values from Mr. Luke's table of distribution and disposal of losses in railway motors. In the columns for one-hour runs we find values for watts loss per pound of motor and also a value for the per cent absorbed. Now if we multiply these two values together we have, the watts absorbed per pound of motor during the one-hour run or the watt-hours absorbed per pound of motor for 75 deg. rise.

This multiplication gives the following results:

60 h. p. inclosed motor	1.96
65 h. p. self-ventilated motor	2.28
25 h. p. self-ventilated motor	1.85
200 h. p. separately ventilated motor	1.93

The average of these values is 2.01 watt-hours per pound. Note that the table covers a wide range of designs from 25 to 200 h. p. inclosed, self-ventilated and separately ventilated. The maximum variation from the average is only 13 per cent. This is fairly close for a quantity of this nature which is rather difficult to determine accurately and which is to be used, as Mr. Luke points out, in an equation based upon the assumption of a more uniform distribution of heat than actually exists. Incidentally this average value of watt-hours per pound of motor from Mr. Luke's table checks almost exactly with a value of two watt-hours that I have used for the past ten years in rough calculations of duty cycles in railway service.

In his conclusions Mr. Luke states that temperature limitation in railway service is found in the hot-spot temperature at peak loads. While this is a perfectly logical conclusion from the calculations presented, there are certain practical considerations that should not be overlooked. Time as well as tempera-

*A. I. E. E. Journal, Vol. XLI, 1922, March, p. 165.

ture is an important factor in the deterioration of insulation. It is a matter of general knowledge that cotton when properly impregnated as required to meet the conditions of Class A material will stand temperature considerably in excess of that specified for Class A material for many days without serious deterioration. In an application where weight of equipment is of such great importance and where peak loads of such severity occur as in railway service it would not be economically correct to limit hot-spot temperatures at peak loads of short duration to the temperatures prescribed for continuous service. We must make some allowance for the element of time.

C. J. Fechheimer: I believe that one of the most interesting things in connection with various physical phenomena is that the equations which are derived for one kind of phenomenon apply to another; for instance, the equation for the magnetic field or for the electrostatic field are known to be very similar and practically identical. I refer to the flow lines and equal-potential lines. The gravitation field, the heat flow field, the hydrodynamic field pertaining to the flow of fluids, are mathematically at least, the same kinds of phenomena.

The particular case in point, in connection with Mr. Luke's paper, is his time-temperature curve equation, which is similar to that of the equation pertaining to the building up of current in an inductive circuit.

Mr. Luke's equation, (using his symbols) is, if the datum for reference be taken as T_s, (that is, T_s is taken as zero for reference): $T_t = T_c\,(1 - e^{-\frac{t}{t_1}})$

The time constant, $1/t_1$, is:

$$1/t_1 = \frac{S_e\, r\, K_e + \dfrac{S_i\, K_i}{1 + \dfrac{0.9\, S_i\, K_i}{V}}}{.06\,(P_a + r\, P_i)}$$

The first term in the numerator represents the watts dissipated from the external surface per degree. The second term will also be seen to increase with the watts loss.[1]

Therefore, the numerator is a factor which is nearly proportional to the watts liberated. The denominator is a constant—depending upon the specific heat times the weights. Therefore, the denominator represents the heat stored. In other words, the time constant, $1/t_1$, is equivalent to the ratio of the energy consumed to the energy stored.

The well-known equation for the growth of electric current in an inductive circuit is:

$$i = I_0\,(1 - e^{-\frac{r}{L}\,t})$$

This equation is in every way similar to Mr. Luke's equation as written above, provided the time constant R/L is similar to the time constant $1/t_1$. This will be seen to be the case, for R/L represents the ratio of the energy consumed indicated by R, to the energy stored in the magnetic field, indicated by L. Thus, i, the current at any instant, is comparable with T_t, the temperature at any instant; I_o and T_c are comparable, both being the values for the steady state.

I want to call attention to the fact, mentioned also by Mr. Luke, that equations of this character can be considered only as approximate. I want to emphasize that point, so that any one using such equations would not be likely to be misled. The conditions might be compared, perhaps, with those which would obtain in the building up of current in an inductive circuit, if the factor L were not a constant, but one which depended on the permeability of the iron. You could see at once how extremely difficult a solution of that problem would be in the electric circuit if the permeability were variable. Some of the uncertainties are that the temperatures are not uniform, and therefore the rates of dissipation of heat are not uniform. We get all values of temperature, for instance, from the outside surface of the motor. Non-uniform temperatures also mean that there are complex internal heat flows—flows from high to low temperatures—which complicate the problem tremendously. Such factors it is next to impossible to incorporate in any mathematical derivations.

The constants entering into the equations are quite uncertain; such as the rates of dissipation of heat from any one of the surfaces. That nominal constant is very much complicated by the effect of eddies in the air. If the air moves in perfectly straight lines, it does not pick up nearly so much heat for a given rise of temperature of the surface above the air as it does if the air is highly turbulent. When highly turbulent, each particle of air comes into contact with the dissipating surface, and therefore each particle serves directly to pick up heat; otherwise, only those particles of air which come into contact with the particular surface are heated directly; with smooth flow, some particles are heated indirectly, that is, by conduction.

As time goes on, as the air-heats,—the mass of air must necessarily decrease, assuming that the volume of air is constant; and as the amount of heat which the air can take up is a function of the mass of air per minute which passes through the motor, the air becomes less effective for carrying away the heat.

Again, the ratio "r" which Mr. Luke has in his equations, is also subject to experimental determination, and a great many tests are required before it can be determined with sufficient accuracy.

However, I do not want, by any means to disparage the value of Mr. Luke's paper, as I think it is quite a valuable contribution. As a matter of fact, the duty cycle of the railway motor is very uncertain; much more so than the factors which come in in the determination of the time-temperature curves. We can approximate sufficiently close for ordinary use, by means of Mr. Luke's equations, the conditions which obtain in general service in railway motors.

I think that if a complete solution were obtained it would be advisable to estimate roughly the influence of longitudinal heat flow in the copper, as well as the transverse heat flow. I attempted to do this in a paper which I read a year ago before the Institute.[2] That solution covers the steady state only; if, in addition, time is considered as an independent variable, the equations become so complicated that a solution is well nigh impossible.

I want to mention two more points; first, the enormous influence of air pockets. This was spoken of in discussing Mr. Shanklin's paper. In the insulating wrappers on coils, whether paper, or cloth, or mica, or what not, there are certain values of thermal conductivities for the individual layers of insulation. If these layers of insulation are put one above the other, as in ordinary practise, it is impossible to avoid tiny air pockets between them. The effect of these air pockets, (or "contact resistance"), is to decrease the thermal conductivity to about half the value which would obtain for the individual layers. This means, of course, that it is far more difficult for the heat to escape as the result of these air pockets than would be the case if they were not present. Furthermore, this decrease in thermal conductivity, due to the voids, makes the determination of temperature more uncertain because the thermal conductivity has a more uncertain value in wrappers, than when the individual layers alone are dealt with.

The other point: We are accustomed to speak of heat dissipated from machinery, or from any other heated body, as radiation. We speak, for instance, of those devices which are the agents for heating our rooms as radiators. As a matter of fact, nearly all the heat is dissipated from them by free convection

1. If 1 be neglected, the second term becomes simply V/0.9,[a constant for a given machine.] If the other term be ignored, the second term becomes $S_i\, K\, i$, = watts liberated om the internal ventilating surface.

2. Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils, TRANS. 1921, A. I. E. E. p. 589.

currents, and only a little by radiation, radiation pertaining to heat waves in the ether. The heat which escapes from the incandescent lamp filament is almost entirely by radiation, because the temperature of the filament is so very high compared with the surrounding bodies, but not so with the heat from an electrical machine. There it is almost entirely dissipated by convection currents. Why should we not speak of the surfaces from which heat is dissipated as "heat-dissipating surfaces" rather than as "heat-radiating surfaces?"

F. W. Peters: From experience I feel that the designing engineers have pretty well mastered the subject of railway motor heating, the topic under discussion in the paper. This is borne out from a practical standpoint by the fact that there are relatively few failures emanating from straight overheating where motors are operated within the service for which they are recommended. Design constants are well known and a reasonable factor of safety used in application to motors with the result that the pure heating situation seems to be quite well taken care of.

However, I wish to read a sentence in Mr. Luke's paper as follows: "Railway motor failures may be classed as mechanical and electrical. A large part of electrical failures is due to poor commutation and flashing or to excessive temperatures."

On the basis of experience with failures of railway motors from a manufacturer's standpoint, it appears that failures because of excessive temperatures are relatively very few in number. Often it is difficult to determine the cause of a failure, and many times erroneous conclusions may be arrived at, because evidence of the primary cause for the failure may be destroyed. A failure, apparently due to temperature, is very often the result of a contributing cause initiated by a mechanical failure. For example, if a coil becomes loosened in a slot and mechanical chafing of the insulation results in an electrical breakdown, it is possible to attribute the failure to excessive temperatures, whereas it is primarily a mechanical failure.

Railway motors are subjected to very severe service with respect to operating under conditions of moisture. We are all familiar with the fact that failures in winter are much greater than in summer. Put two similar motors in equivalent service with one operating under severe moisture and the other under dry condition, the former motor would be expected to fail in a shorter time than the latter because of water and the dirt carried with it which more rapidly harms the insulation. While the heating conditions for the two motors are identical we would expect shorter life on one than the other because of an outside contributing cause. When such a motor fails it may be attributed to excessive temperatures, whereas it may in reality be due to the severe mechanical conditions to which the insulation has been subjected.

Other failures that we have to contend with are those caused by flashing which may harm the insulation, and on the occasion of a burnout may make it appear that excessive temperature was the cause; whereas the failure was accelerated by an abuse of the insulation.

A. C. Lanier: Mr. Luke's paper has brought out in a very interesting fashion the possibility of approaching what is rather a complex problem in a rational way, and getting results which are simple and yet dependable within reasonable limits. When conditions affecting heat dissipation are known, such as the losses and their distribution, the weights of material which absorb the heat energy, the volume of cooling air available, and the extent and character of the surfaces with which that air comes in contact, probable temperature rises may be predicted under known sets of conditions.

The same method of approach would very naturally suggest itself for motors in ordinary industrial applications, but with the ordinary industrial motor, some difficulties enter which are absent or less pronounced in the case of the railway motor. Of course, there is relief, on the other hand, from a good many difficulties which the railway service imposes. If we consider, for example, the open motor with natural ventilation, we find considerable variation in the ventilating characteristics even of individual machines of the same general line. For example, there is a difference in the effectiveness of multiple turn coil and single turn coils; this difference seems chargeable both to unequal fanning action, and unequal amounts of coil end surface exposed to the convection currents of air. Frequently with different motors and different coils, the flow of air is not found with any great degree of definiteness, it is very variable,—you might find different parts of the motor resisting rather than contributing to a definite air flow.

When the question of degrees of enclosure is introduced, the problem of ventilation and temperature rise is further complicated and is rendered still less definite. With total enclosure, the total external radiating surface of the motor sets a fairly definite limit to the losses which may be dissipated. With partial enclosure there is not only a reduction in the amount of cooling air carried into the motor, as compared with the open type, but its direction of flow may also be considerably modified.

I should think, however, that though a larger number of constants might be necessary in applying these general relationships, which Mr. Luke has given to the ordinary industrial motor with natural ventilation, still with sufficient experimental data, his method might work out very well. I should like to know whether Mr. Luke has extended his investigations into the field of motors in industrial applications.

G. E. Luke: Mr. M. R. Hanna has shown that the watt-hours absorbed by the motor at the one-hour rating are approximately equal to two watt-hours per pound of motor and is practically independent of the type or degree of ventilation. Mr. Hanna mentioned the fact that insulation life is affected by not only high temperatures, but also by the time these temperatures existed. This point is well taken, since tests have been made under load conditions which caused the insulation to "smoke," involving temperatures ranging from 175 to 200 deg. cent for a few minutes duration. Examination of the insulation (Class A) showed it to be still in good condition. However, there is no doubt but that continued application of these high temperatures would soon cause failure. For example, tests on Class A insulation at 150 deg. cent. for three months rendered it lifeless as far as mechanical strength is concerned.

The poor thermal conductivity of insulating materials due to air pockets in the built up material was mentioned by Mr. C. J. Fechheimer. Proper impregnation of the insulation will reduce these high resistance paths to the flow of heat. Dipping and baking of the armature and fields is also beneficial in making the insulation more compact and homogeneous.

As stated by Mr. Fechheimer, radiation plays a minor part in the cooling of electric motors. For example the factor of 0.013 has been previously given as the watts *dissipated* from the external surface of a railway motor frame in watts per square inch per deg. cent. rise. This is the resultant of radiation, natural convection and a very small factor due to conduction through the motor supports. Of this constant (0.013) 20 to 30 per cent is due to radiation, and the remainder is mostly the resultant of natural convection.

Mr. F. W. Peters brought out the fact that a relatively small percentage of failures is caused by roasting or excessive heating of the insulation. Fortunately this fact is true especially when the motors are not loaded beyond the limits recommended by the manufacturer, and when weather conditions are not abnormal.

However many cases develop where a motor must be overloaded in order to maintain the schedules in an emergency. It should be clearly understood that on such abnormal overloads if failure occurs it is apt to be due to overheating since the factor of safety used from a mechanical standpoint is much greater than that feasible from the heating standpoint.

The purpose of this paper was to bring out the temperature

limitations of the motor under different load conditions so that the lightest motor economically possible, consistent with satisfactory operation, could be used.

Prof. Lanier asked whether the method of calculation of temperature could be applied to industrial motors. The method as mentioned in the paper is more applicable to separately ventilated motors, where the air conditions are more definite, since the air is restrained to move in more or less definite paths. In the case of industrial motors where the machine is cooled by natural convection currents or the fanning action of the armature ducts and end windings, the conditions of ventilation are not definite enough to calculate with any degree of accuracy, from the fundamental physical conditions. However, if one continuous rating is known, other ratings on the same machine may be calculated at different loads and speeds as explained in the paper for self-ventilated motors.

THE INDUMOR*

(Karapetoff), New York, N. Y., February 17, 1922

Lawrence E. Widmark: We have lately been presented with two mechanical devices to replace the Behrend-Heyland Circle Diagram, one from Cornell University and the other one from Yale, and I would like to say a few words in defence of the old diagram.

We all know that the chief trouble with this diagram has been that where high precision is most desired the lowest one is obtained, depending on "that little lower left hand corner," you know, where the characteristics of the ordinary running conditions are to be found. Now, seeing the Yale device this thought suggested itself: "Have we to go to all that trouble to overcome these difficulties?" Well, at the Star Electric Motor Co. we have had in successful operation an arrangement of the diagram which I think meets requirements.

As a matter of fact, the Behrend-Heyland diagram employs

Fig. 1

a circle of *varying size* for every separate case which circle is fitted into a *fixed* coordinate system. We have reversed this procedure and are using a *fixed circle* and a *variable coordinate system*, varying with the impedance. This arrangement makes possible the "standardized diagram sheet" which I am showing here. The purpose of the larger circle is to give an enlarged view of the ordinary load conditions and the smaller one to get the maximum load and torque values in a scale just sufficient to give the desired information.

As an extra advantage of this diagram I have found interesting possibilities in respect to motor design in general which I think measure up to those promised by Prof. Karapetoff's machine. Besides this, the new diagram facilitates corrections for primary drop and saturation.

Prof. Karapetoff in his device also is able to take care of the primary drop. Neglecting saturation is, however, more questionable as I think that most of us motor designers would in a short time be out of business if we did not pay due respect to this condition.

H. M. Hobart: I do not think that the time-saving element in Prof. Karapetoff's device is its principal advantage. I believe that its use should lead to obtaining better designs. Many years ago designers felt that they had reached the ultimate best design, or had come pretty near to it. But succeeding years have always brought forth cheaper or better designs; usually designs which were *both* cheaper and better. This process continues, and the limit does not appear to be in sight. I believe that the progress toward the limit is slow largely because of the labor of preparing and comparing enough alternative designs to clear our minds on the subject. One who is designing an induction motor, for a certain rating works through half a dozen designs for comparison. By that time he has expended so much time and labor that he is tempted to conclude that the best design he has been enabled to arrive at by that amount of calculating must be about the right one to build. But by these new methods of Prof. Karapetoff, you can go far more extensively into the subject. You can study a much greater range of combinations and you can introduce a great many modifications and much more clearly guide your mind than when you are all tired out through laborious step by step calculations. You can much more intelligently take into account the relative influences of the many variables and limitations that are involved.

It is for these reasons that I have not the least doubt that with the introduction of these mechanical methods, the chief advantage will not be the saving in labor, but the more rapid evolution toward both cheaper and better designs. I see in the room an engineer who some six or more years ago showed me some mechanical machinery he was getting up for designing transformers, and I, at that time, was exceedingly enthusiastic for this very same reason, namely, not so much that it would save a great deal of time in calculations, but that it would lead more quickly to better and cheaper designs for a given rating. That engineer found that he did not have time enough to give to this, as it was a sort of side interest with him, but he had already at that time carried his machine to an encouraging stage of completion. I see another engineer here who, together with his colleagues has done a great amount of such work, in connection with electro-mechanical methods of calculating transmission lines.

I mention this as suggesting, perhaps, that we are at the beginning of an era of solving many complicated problems by mechanical methods, and I want again to emphasize that the most important object in these methods, in my opinion,—although it is important to save time,—is the obtaining of much better results, better economies and better characteristics of the machines.

P. Trombetta: I recognize with great respect Professor Karapetoff's very ingenious device. Unfortunately, however, it is not as easy as it might seem to change one constant of a motor without changing all the rest and this is due to the fact that the distribution of magnetism can not be restricted to any given circuit in a similar way that we can restrict the flow of electricity, and to the additional fact that the permeability of iron is not constant. Therefore, when Prof. Karapetoff states that if he wishes to change the characteristics of a motor, all that is necessary is to change the length of the particular lever which represents that particular constant which we wish to alter, he forgets the fact that by varying that constant all the rest of the constants are automatically changed. For instance, suppose it is desired to change the internal resistance of a motor, it is found that both the dimensions and configuration of the tooth and slot are altered with the resistance, which alterations give rise to changes in leakage reactance, magnetizing current, power factor, heating and so on, which may in turn make it necessary to vary the pole pitch, the diameter, the axial length of the cores and the new characteristics obtained by the indumor would therefore be meaningless.

On the other hand, in case of the calculations of line constants, in which the magnetism around the line conductor flows only through air, the permeability of which is constant, this apparatus may prove to be of great value.

*A. I. E. E. Journal, Vol. XLI, 1922, p. 107.

V. Karapetoff: Mr. Widmark has apparently developed an improvement in the circle diagram, and I am the first one to welcome it, because I fully appreciate the wonderful usefulness of the circle diagram. I am offering a new computing device, not to supplant anything that exists, but merely something that might in some cases be also useful.

In connection with the circle diagram, I want to say that recently we have done at Cornell University something that may also add a new lease of life to this useful method, the circle diagram; namely, we have found an easy method of determining additional points on the circle diagram. In a large motor, the center of the circle lies at the same height above the axis of abscissas as the no-load loss line, but in the case of a machine with an excessive primary loss, the center of the circle lies in a different position. For such machines it is desirable to determine experimentally a third point on the circle, in addition to the no-load and the short-circuit points. We have found that it is very easy to determine the point of maximum power factor. We connect a power-factor meter in the motor circuit, and let the motor run up to speed at no-load, or else we load it until it stops. An observer follows the pointer of the power-factor meter, with a pencil, and when the pointer commences to go in the opposite direction, he leaves the pencil at that point. This gives him the maximum power factor, and a tangent to the circle. Therefore the circle can be drawn much more definitely.

I am glad that Mr. Widmark brought up the question of saturation. We have been lately working on a similar device (named the Blondelion) to imitate the performance of the synchronous machine, both the generator and the motor. In a synchronous machine it is, of course, necessary to have the saturation in the magnetic circuit properly taken into account. I am happy to say that we have solved this problem, completely so that almost any saturation curve can be imitated with that device. For highly saturated induction machines this additional linkage may be incorporated in the Indumor.

Now as to whether or not transmission lines could be treated in the same way: We have a device practically completed which imitates perfectly the performance of a long transmission line with distributed constants. We have named this device the Heavisider, after our honorary member, Oliver Heaviside. The problem is not as difficult as it may seem, and it is possible to represent kinematically the regular performance of a long transmission line without complex quantities or hyperbolic functions. The problem that interests me now is to develop a device which would represent transient phenomena on a transmission line, and not established conditions.

In conclusion I wish to point out the existence of certain useful analogies in different branches of natural science, analogies which help in the solution of certain problems. For example, take a direct-current network with known resistances and voltages, and with unknown currents. To determine the unknown currents, we have to write down and to solve a system of linear algebraic equations. Now reverse the problem,—let in a problem (which may not be an engineering problem at all, agriculture, finance, or what not) a system of simultaneous equations be given. You can connect an electrical network in which the constants of the problem will be represented by given resistances and e. m. fs., then you can insert an ammeter in each branch and read the currents. You have thus solved electrically a problem which has nothing to do with electricity.

The other day a client wanted me to solve for him a problem in mechanical oscillations. I looked at the differential equations and I saw at once that an electrical system could be built which would be expressed by similar equations. I told him that we could build for him an electric system, insert a galvanometer, follow the oscillations of the galvanometer needle, and that such a device would give him the desired information about the mode of oscillation of his entirely different mechanical system.

SKIN EFFECT AND PROXIMITY EFFECT IN TUBULAR CONDUCTORS*

(Dwight), New York, N. Y., February 17, 1922.

E. W. Davis: Many learned and excellent papers have been presented before this society and other physical or technical societies, on the subject of skin effect in conductors carrying alternating currents. These papers have not, however, been interpreted for the average engineer to understand.

For radio frequencies and small sized conductors, theoretical formulas have been checked and it has been assumed that these formulas would apply to larger conductors at the lower power frequencies.

Except in the paper of Mr. W. I. Middleton's and the speaker's the data of tests conducted on actual commercial power cables at the low frequencies of 25 and 60 cycles have not been published as far as the speaker has been able to determine.

Tables furnished by manufacturers or put out by engineers of purchasing companies calling for rope cores in power cables show a remarkably wide variation in the size of cores for the same working conditions. Each table is based on some theoretical mathematical formula that is probably quite as correct as the one worked out by Mr. Dwight.

One of the simplest conceptions of skin effect and one that is quite universally used in elementary text books on electricity, is that of the depth of penetration of alternating current from the surface of a conductor. Most of us remember our high school or college instructors saying that an alternating current travels on the outside of a conductor. Alexander Gray in "Absolute Measurements in Electricity and Magnetism" gives a very interesting discussion of this conception of skin effect.

The experimental work of Mr. Middleton and the speaker in 1921 was done on commercial power cables at commercial frequencies, for the purpose of furnishing engineers with specific experimental information on the subject of skin effect in power cables. The work was done for a specific purpose, and that purpose was accomplished. The results published are quite trustworthy for the range of sizes tested and at some later date we hope to continue our tests on even larger sizes of conductors.

The constant 0.00384 used, and to which Mr. Dwight takes exception, was checked for the copper used in the actual construction of the cables.

We do not necessarily recommend the rope cores given for the smaller sizes of conductors at 25 cycles, but include them in our paper merely as an example of what these cores should be, if used.

A. S. Dana: I wish to call attention to some measurements which were made at the Massachusetts Institute of Technology in the year 1915, and which were determined to a considerable degree of accuracy under the guidance of Dr. A. E. Kennelly. The results on a 7-strand, 19- and a 37-strand are very different from those found by Middleton & Davis. The 7-strand cable, as I understand it, in the Middleton & Davis[1] paper has a much smaller skin effect than a solid conductor cable of the same cross section. The mean value measured by Davis 1.089 at 500 cycles, but that of a solid wire of approximately the same copper cross section is 1.293, or the skin effect Mr. Davis found on a 7-strand cable was about 20 per cent less than that of the equivalent solid wire. Mr. Dwight ascribed this large difference to an error in Mr. Davis' measurements. At frequencies above 1250 cycles and 60-cm. spacing of the return conductor Mr. P. H. Pierce found the skin effect of 7-strand cable was greater than the solid. I think Mr. Pierce in a publication[2] previous to 1915 was the first to note and publish this effect. Dr. Kennelly desired me to check these measurements on 7-strand, and solid wire in 1915. I found that the skin effect of a 7-strand conductor is greater than that of the solid conductor above a certain frequency depending on the spacing of the return conductor, and the paper by Kennelly & Affel[3] at radio frequencies proved the same conclusion, and the cause was ascribed

*A. I. E. E. Journal, Vol. XLI, 1922, March, p. 203.

to the spirality effect. The spirality effect was later taken up in more detail and Mr. Dwight has gone still further.

I think it is generally considered that by stranding a conductor the skin effect is reduced as the number of strands is increased (providing the number of strands is greater than 7). On the 19-strand and 37-strand cables we found this to be the case: the skin effect was less than in a solid conductor of the

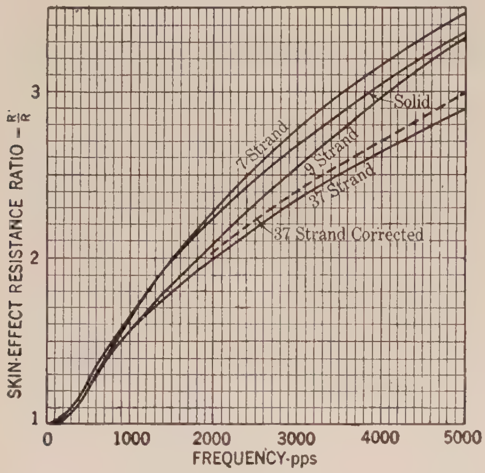

Fig. 1—Effect of Stranding on Skin-Effect

Separation approximately 60 cm., No. 0000 B & S Copper Cable. The 37-strand cable has smaller cross section than the others. Curve "37 Strand Corrected" takes this into account.

same cross section, and also the skin effect of the 37-strand was less than the 19-strand. I have obtained permission from the Institute to publish these results from 60 to 5000 cycles since I think that they may be of value to other people interested in this problem. They appear in Figs. 1, 2, 3, 4, 5, 6. Each cable was measured in the form of a rectangle with three differ-

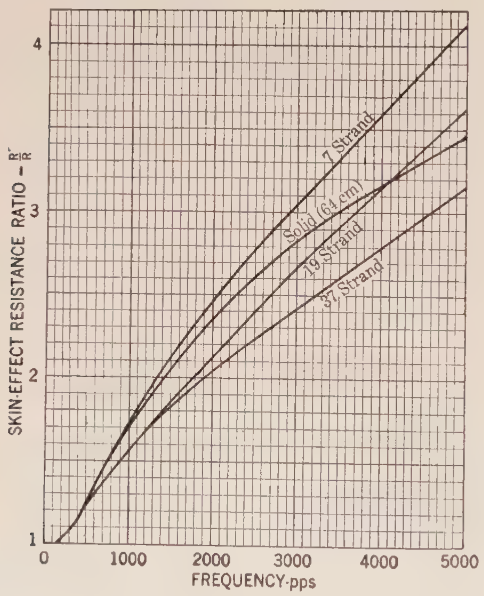

Fig. 2—Effect of Stranding on Skin-Effect

Separation approximately 2.4 cm. No. 0000 B & S Copper Cable. Temperature of Cable—Solid, 20.3 deg. cent.; 7-Strand, 15.6 deg. cent.; 19-Strand 27 deg. cent.; 37-Strand, 29 deg. cent.

ent spacings of the long sides. The effect of the return conductor was negligible at 60-cm. spacing.

Middleton & Davis, however, found just the opposite to be the case; *i. e.*, the greater the number of strands at 500 cycles the greater the skin effect. It is not safe to draw general conclusions from these measurements since at higher frequencies where more accurate results may be obtained, it is clear from the accompanying curves in Fig. 1 that the skin effect grows less as the number of strands is increased (above 7). Mr. Dwight[4] cast

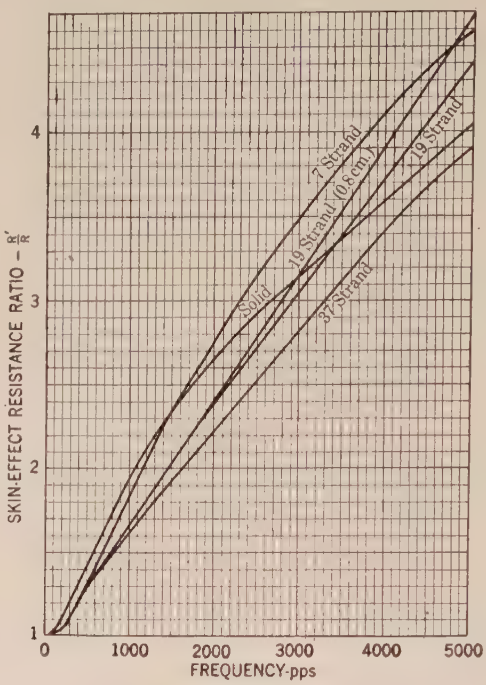

Fig. 3—Effect of Stranding on Skin-Effect

Separation approximately 0.9 cm., No. 0000 B & S Copper Cable

doubt on all the Middleton-Davis measurements and their conclusions, for the measurements of the same skin effect varied by 8 per cent. Those made by Pierce and myself were repro-

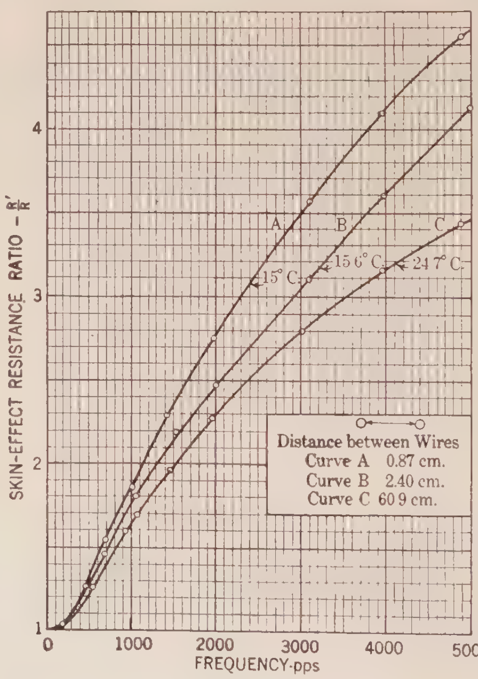

Fig. 4—Skin Effect of 7-Strand Copper Cable, 211,700 cir. mils

Distance between wires—Curve *A*, 0.87 cm.; Curve *B*, 2.4 cm.; Curve *C*, 60.9 cm.

ducible to better than 1 per cent and usually better than ½ per cent.

There is one thing more I would like to say—it may be an unfortunate choice of words, but Mr. Davis speaks of the pene-

tration of the current as being only to a certain distance from the exterior of the conductor. This is not true, for the current goes to the center. However, it decreases at a great rate, starting from the circumference, and what is usually meant is

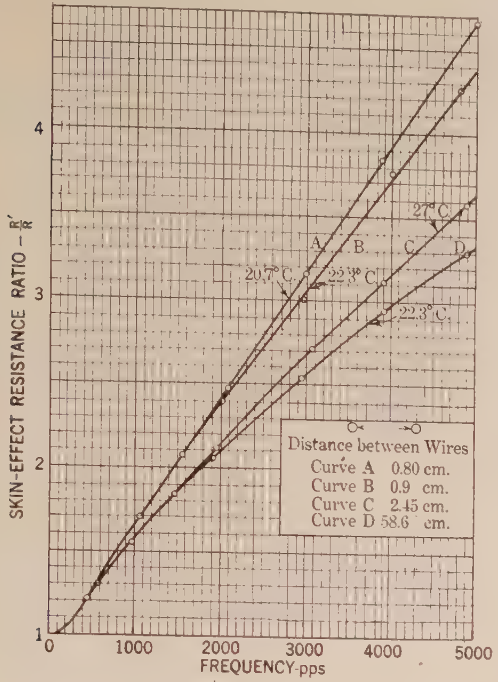

Fig. 5—Skin Effect of 19-Strand Copper Cable, 210,700 cir. mils.

Distance between wires—Curve *A*, 0.80 cm.; Curve *B*, 0.9 cm.; Curve *C*, 2.45 cm.; Curve *D*, 58.6 cm.

that a tube having a thickness equal to this "penetration" of which they speak, will offer the same resistance to direct current, that the complete solid conductor offers to alternating current. Furthermore, I believe in the Middleton-Davis tests

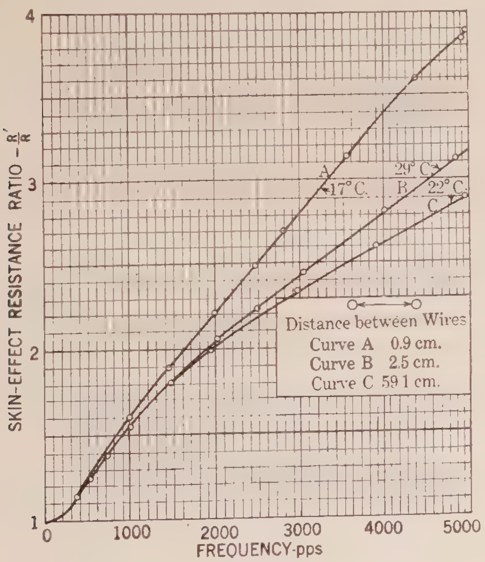

Fig. 6—Skin Effect of 37-Strand Copper Cable, 198,200 cir. mils.

Distance between wires—Curve *A*, 0.9 cm.; Curve *B*, 2.5 cm.; Curve *C*, 59.1 cm.

they took solid conductors, computing this depth of penetration, or the equivalent conducting layer, and decided that the material inside this ring could be thrown away and rope substituted, giving approximately the same a-c. resistance.

You will find that this may be practically true in some cases where the diameter of the conductor and the frequency are high, but at the lower frequencies, the conductor with the center removed would have a greater resistance than the completed conductor.

For the benefit to those who care to use Gray's formula which was employed by Middleton & Davis, I think it should be pointed out that this formula is an approximation and only for use when the diameter of the conductor is so large or the frequency so high that the wire can be considered a strip of infinite width, or a tube of very small thickness. This formula does not contain any symbol for the radius of the wire, and would lead one to think that the depth of the equivalent conducting layer is independent of the radius of the wire, and varies only with the frequency and the conductivity. Using the notation which Dr. Kennelly has used in the three papers[2,3,5], I wish to call attention to the fact that the product of αX must be 6 or greater to use this formula with approximate accuracy. With the 2,000,000-cir. mil cable with an outside diameter of 1.625 in. in the Middleton & Davis paper at 60 cycles this product of αX is only about 3.42 instead of being greater than 6, hence that formula should not be used unless these conditions are understood, and only a rough result is desired. A formula for the equivalent skin thickness of any wire is given by Dr. Kennelly[2], page 790. In this the radius of the wire has an important part.

Bibliography

1. W. I. Middleton and E. W. Davis. "Skin Effect In Large Stranded Conductors at Low Frequencies." Journal A. I. E. E., Vol. XL, No. 9, Sept. 1921, p. 757.

2. A. E. Kennelly, F. L. Laws and P. H. Pierce. "Experimental Researches on Skin Effect In Conductors." Trans., A. I. E. E., Vol. XXXIV, Part II, p. 1953.

3. A. E. Kennelly and H. A. Affel. "Skin Effect Research Measurements of Conductors at Radio-Frequencies Up to 100,000 Cycles." *Proceedings of the Institute of Radio Engineers*, May 1916, p. 523.

4. H. B. Dwight. "Skin Effect and Proximity Effect in Tubular Conductors." Journal A. I. E. E., Vol. XL, No. 3, March 1922, p. 203.

6. A. E. Kennelly, F. H. Achard and A. S. Dana. "Experimental Researches on Skin Effect in Steel Rails." *Journal of Franklin Institute*, Vol. 182, No. 2, August 1916, p. 135.

H. B. Dwight: In dealing with the problem of the skin effect in a conductor of a given form of cross-section, it is necessary to try to make all the measurements which have been made with that form of section, consistent with each other. There is no doubt that they ought to be consistent, for the phenomenon of skin effect in a non-magnetic conductor at high frequency is caused by a magnetic field of the same shape as that surrounding a similar conductor in a low-frequency test.

The way in which high-frequency tests can be compared with low-frequency tests to see if they are consistent is to correct them for frequency according to the "principle of similitude," described in the third and following paragraphs of my paper.

Mr. E. W. Davis, in the second paragraph of his discussion, states that it has been "assumed" that the same laws apply to high-frequency and low-frequency tests. The principle of similitude is not an assumption. The writer gave definite reasons for it in his A. I. E. E. paper in 1918 and Mr. J. Slepian published at the same time a conclusive mathematical proof of it. (Reference 1.) If, therefore, any one should wish to cast doubt on this principle, the burden of proof is on them, and they should show evidence, either mathematical or experimental, that the principle of similitude is not true.

The question of whether the penetration formula should be used in connection with large conductors at commercial frequencies is best considered by using a direct comparison between the results of this approximate formula and the correct results, as shown in the Fig. 7. The range required for large

60-cycle cables is up to 30 per cent increase of resistance. In this range it can be seen that the penetration formula gives 37 per cent increase of resistance where it should give 30 per cent. It gives 26 per cent where it should give 20 per cent, and it gives zero per cent where it should give 3 per cent.

Such large discrepancies show that the penetration formula does not give a close approximation for the range considered. If a calculation is to be of use in deciding questions of design of large cables, it should not give errors as large as 7 per cent in a quantity which amounts to not more than 30 per cent. The same statement applies to test results having discrepancies between duplicate readings amounting to several per cent.

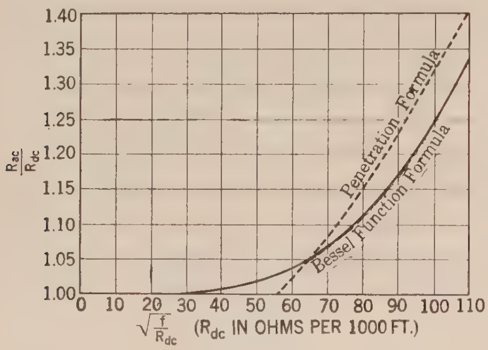

FIG. 7—SKIN EFFECT IN SOLID ROUND WIRE

The penetration formula was originally published by physicists who were discussing skin effect at high frequencies with increases in resistance of several hundred per cent. Under such conditions, the error due to the penetration formula is quite small.

If a series of rope core sizes is to be chosen for 25-cycle and 60-cycle cables, which shall be consistent with each other, the sizes of rope cores should have a definite relation to the improvement in skin effect obtained by using rope cores. The sizes of cores should therefore have a definite relation to the difference between the skin effect in the coreless cables, as given by the Bessel function formula, and the skin effect in the tubular conductors formed by the cables with cores, as given by Fig. 1 of my paper.

The sizes of cores will be very inconsistent if they are chosen as was done in the paper by Middleton and Davis, in accordance with skin effect values in coreless cables given by the penetration formula, and the incorrect assumption that the skin effect increase in resistance in the tubular conductors formed by the cables with cores, is zero per cent.

It is rather surprising that Middleton and Davis made no measurements of the skin effect in cables with rope cores, for that is the type of conductor whose design they were investigating.

In making future skin effect tests, I would suggest, since accurate tests results are so hard to obtain, that the instruments be first checked by measuring the skin effect in solid round rods. This has been calculated, and the calculations checked closely by measurements all the way from 60 cycles to 100,000 cycles. After it has been shown in this way that the instruments give correct and precise results, they can be used to measure the skin effect in more complicated conductors, and the results would be considered trustworthy if the conditions of testing the solid rods and the other conductors were substantially the same.

CURRENT LOCUS OF SINGLE-PHASE INDUCTION MOTORS*

(KOSTKO), NEW YORK, N. Y., FEBRUARY 17, 1922.

V. Karapetoff: Mr. Kostko deserves much credit for having consistently followed what may be called a graphico-analytical method of solution of the single-phase induction motor, without the use of complex quantities. He is somewhat in the position of an arctic explorer who went to verify indefinite rumors about a favorable passage, and proved concisely that there was none. Someone had to do it, but few will appreciate the real value of a contribution consisting of a negative result. To me Mr. Kostko has proved only that by the method which he adopted no particularly useful results can be obtained either for a designer, an operating man, an experimenter, or a theoretical investigator. In order to use his results intelligently, one has to study carefully about twelve columns of weary mathematics and several complicated geometric figures. And when one finally arrives at the end, one finds the familiar old fact that the no-load and short-circuit tests alone do not determine the circular locus. It is necessary to use approximate relationships and empirical coefficients as given in his paper.[1] The limits of validity of these assumptions, or the magnitude of error committed, would be difficult to estimate, especially with a new motor of unusual constants.

To me the present situation and the possible future progress in the quantitative theory of the single-phase induction motor seem to be as follows:

(*a*) *The "one variable" diagram.* The difficulty with either the rotating-field or the cross-field theory of the single-phase induction motor is that both lead to equivalent diagrams with two variable branches. Thus, in Mr. Kostko's Fig. 1 one branch has the variable quantity $r_2/2\,s$, and the other has $r_2/2\,(2 - s)$, where s is the variable slip. It has been shown some time ago that the single-phase motor may be replaced by an equivalent diagram with one variable branch only (see V. Karapetoff, JOURNAL of the A. I. E. E., Vol 40, 1921, Aug., p. 641. Fig. 3). This diagram admits of a much simpler analytical or graphical treatment than either of the two usual diagrams, and should be used in the future.

(*b*) *The circular locus.* In the "one variable" diagram mentioned above, the admittance of the variable branch is $s\,(2 - s)\,Y_c$, where s is the slip and Y_c is a constant admittance which characterizes a given motor. Thus, the locus of the variable admittance is a straight line in the direction of the vector Y_c. A constant admittance, $(X + Z + r)^{-1}$, is added in parallel to this admittance, still leaving the straight-line locus. The first inversion gives a circular locus for the equivalent impedance. Two more inversions are necessary to account for the remaining constant parts of the circuit, but the inverse of a circle is also a circle so that the final result is a circular locus. This is the simplest exact proof of the circular locus of the single-phase induction motor that I know of. No complicated analytical or graphical proof is necessary.

I have shown on another occasion that it is not necessary to change the circle at each successive inversion, but that the first circle and the last circle can be made to coincide by properly changing the scale (See Sibley *Journal of Eng'g* Vol. 32, 1921, p.42). Therefore, for a single-phase induction motor of given constants it is now possible to construct a circle diagram of a current, with hardly any computations, except for measuring a few lengths and taking their reciprocals. This diagram also inherently contains slip values. Knowing the primary current, its phase angle, and the corresponding slip, it is not difficult to compute the remaining characteristics.

(*c*) *The analytical method.* The same new equivalent diagram, mentioned above, leads to the following expression for the equivalent impedance of a single-phase induction motor:

$$Z_{eq} = Z_1 + \left[Y + \{ X + [(X + Z + r)^{-1} + Y_c\, s\,(2 - s)]^{-1} \}^{-1} \right] \quad (1)$$

In this formula all the quantities are motor constants, expressed as complex numbers, and the only variable is the slips s, By giving different values to s, the values of Z_{eq} can be computed, and the corresponding values of current vector found by dividing the applied voltage by Z_{eq}. It is true that at the present time

*A. I. E. E. JOURNAL, Vol. XLI, 1922, January, p. 30.

1. A. I. E. E., JOURNAL Jan. 1922, p. 35. first column.

numerical computations with complex quantities are somewhat tedious, but then one has the advantage of using a formula which contains only standard operations of addition of impedance in series and admittances in parallel. One does not have to study a complicated analytical theory with special vector diagrams, several angles, simplifying assumptions, etc.

Formula (1) probably represents the simplest analytical expression for the motor in question, since it corresponds to a diagram with but one variable branch. Our next problem is not so much to simplify this expression as to devise a simpler method of computing complex quantities. At the present time the most convenient method seems to be to use the trigonometric or exponential form for multiplication, division, and reciprocals; and to use the orthogonal form for addition and subtraction. The writer has constructed a chart and a device (vectrometer) by means of which changes from one form to the other takes less time. The final solution of the difficulty should be a computing machine made to add and to multiply complex quantities directly. Such a machine would be very useful in many computations relating to a-c. machinery and circuits.

(*d*) *The circular locus from a test.* It is a well known fact that the no-load and short-circuit tests alone are not sufficient to determine the circular locus of either a polyphase or a single-phase induction motor, since a circle has to be determined by three points. In large and medium-size polyphase induction motors of usual proportions the center of the circle usually lies on a certain horizontal line determined by the no-load losses, but for small single-phase motors this assumption is not permissible (See for example, Mr. Kostko's Fig. 7).

The tangent from the origin to the circle determines the point at which the power factor is a maximum and this may be a convenient additional datum to make the circle definite. I know from experience that this method works well on a small polyphase motor. To obtain this value, a reliable power-factor meter is connected in the motor circuit and watched while the motor is coming up to speed, or while it is being loaded. It is easy then to read the maximum value which the power factor reaches. The speed or the slip may also be read at the same time. This test gives the direction of the tangent from the origin to the circle, and together with the no-load and short-circuit point determines the circle itself, and the ampere-speed characteristic.

If a power factor meter is not available, a wattmeter may be used and read at its maximum indication, as the machine is loaded. This will give the horizontal tangent to the circle, and thus furnish the necessary additional information for drawing the circle itself.

J. L. Hamilton: Mr. Kostko attempts to get a little more accurate analysis of the single-phase induction motor. It is doubtful if there is any electrical problem more difficult of solution than this one.

The "Tilted Diagram" gives slightly more accurate results on very small single-phase motor of one-half h. p. and smaller. For larger size motors the accuracy is not improved very much, by using the diagram.

The present writer has used a number of refinements in applying the circle diagram to the small single-phase motor, and has always found that it is questionable if increased accuracy is obtained. We believe, therefore, that it is better to use the simplified diagram as slight variations in the construction of the motor and slight differences in the temperature of the motor will effect the performance, to such an extent as to make too many refinements in calculation useless.

The present writer has for a number of years used the simplified diagram for single-phase motors as is covered in a paper presented before the A. I. E. E.[2]

It is important, however, to have a clear understanding of the assumptions, and approximations used in making calculation. Mr. Kostko's paper deals with some of these approximations in a very definite manner.

[2] A. I. E. E. Trans., Vol. XXXIV, 1915, Part II, p. 2443.

J. K. Kostko: The remarks of Prof. Karapetoff and Mr. Hamilton are a good illustration of what a writer on technical applications of mathematics has often to contend with if his readers look at the subject from different points of view. In Prof. Karapetoff's opinion the diagram is of no particular use to anybody because it is impossible to estimate the error committed on certain quantities. Mr. Hamilton considers the same diagram in the light of experience with actual motors of a certain range and decides that not only this error, but the quantities themselves are negligible, so that an even less accurate diagram is satisfactory.

The no-load and locked tests do not determine the diagram; it must be based on some assumptions. Prof. Karapetoff's contention seems to be that if the limits of validity of these assumptions, or the magnitude of error committed, are not known the diagram is worthless; this condemns all diagrams based on two fundamental tests only, because these tests do not give sufficient data with which to estimate the error; in particular, we should, logically, discard the ordinary non-tilted diagram, polyphase or single-phase, in which the simplifying assumptions are pushed to the extreme, or, at the best, concede to it only the doubtful value of a "contribution consisting of a negative result."

If the range of motor constants (or, rather, of their ratios) were such as to make necessary either a quantitative study of simplifying assumptions, or taking of load points* in addition to the two fundamental tests, the prospects of the circle diagram would be very poor indeed. Fortunately, the range of these ratios is, in reality, rather small; thus, the ratios determining the angles β and γ (Fig. 2 of the paper) are small, *i. e.* the angle of tilt $\beta + \gamma$ is small; this approximate condition, added to the two exact ones given by the no-load and locked tests, determines the circle if small errors on β and γ are neglected. The diagram of the paper is based on this fact; in other words, the simplifying assumption consists in neglecting small errors committed on small quantities—an error of the second order of magnitude, as it were; its exact value is not known, but it is very small, and that is all we need to know. Tests on motors from 1/10 h. p. up (occasionally as low as 1/30 and 1/20 h. p.) fully bear out these conclusions; it is never necessary to use additional points to determine the locus.

Prof. Karapetoff gives some details of his diagram in which the independent variable is the slip, and the output is obtained by calculation; in my diagram the independent variable is the output. Theoretically, the two diagrams are equivalent; but for the applications the slip diagram alone has little value because only in exceptional cases the performance is required for a given speed; the problem nearly always is to determine the performance for a given output. The slip diagram, to be useful, must be accompanied by a set of calculated performance curves, which is a useless burden in many cases where only a few definite points are of interest. I think that it is better to add a few pages of "weary" mathematics for the sake of simple and immediately applicable final results, rather than to preserve the simplicity of the theory by omitting an essential part of it, and oblige the user to go through weary calculations each time a diagram is made.

I agree with Mr. Hamilton that there is little advantage in the use of the exact diagram above 1/2 h. p. (4 pole). The use of the tilted diagram can be facilitated by a gradual extension of simplifying assumptions as follows: (1) exact diagram; (2) point A coincides with the no-load point; (3) same as (2) and negligible rotor resistance, angle $\gamma = 0$; (4) same as (3) and negligible stator resistance, *i. e.* non-tilted diagram.

*The two methods of tangents proposed by Prof. Karapetoff would be of limited usefulness in the case of single-phase motors; the first is always applicable, but requires the use of a very special instrument; the second is simple, but seldom applicable where it is needed, *i. e.* in high resistance, high tilt motors, because the top of the circle in this case usually lies on the arc between the points s = one and s = ∞ and does not correspond to any state of performance.

Electrical Precipitation of Solids From Smelter Gases

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Review of the Subject.—*The fundamental principles of the process in its simplest form are set forth. It is shown why the Cottrell process during recent years has in a large measure supplanted the bag-house and dust chamber in treating smelter gases.*

The commonly accepted theory concerning the manner in which the dust particles is charged and precipitated is given. It is pointed out that the thing most important to the operating man is how the particles may be enabled to give up their charge to the electrodes under all conditions, rather than the manner in which they receive it.

The various types of treaters in common use are described and discussed. The advantages of straight line treaters over those in which the gases are by-passed are emphasized.

It is shown that the gas is ionized much more efficiently for a given power consumption and the construction simplified and reduced by arranging the electrodes in the flue so that their electric fields are in series with each other. It is shown that this is accomplished by causing the gas to flow parallel to the electrostatic lines instead of at right angles to them, as in all other types.

The factors of lead and copper metallurgy are given which control the amount of sulphuric acid and water vapor in the gases. It is also pointed out that these things are a measure of the successful operation when treating smelter gases.

The physical rather than the chemical structure of the dust in suspension is shown to be the all-important matter. Several theories are given as to why flue dust is so much easier precipitated than fume. A number of photo-micrographs are given to illustrate the difference in physical structure between fume and dust.

Two methods are featured of obtaining sufficient conductivity in a dry precipitated coating to permit the electric charge to leak through it to the electrode. The theory of selective absorption is advanced as an explanation of how aqueous vapor added to the gas stream functions in this respect. The method of adding very finely atomized sulphuric acid is shown to be the most practical, it not having certain disadvantages of the water and its higher boiling point permitting a wider field of application. Its action is shown to be due to the fine acid particles being precipitated with the dust particles thereby imparting conductive film to the particles by diffusion.

The amount of free sulphuric acid in grams per 1000 cu. ft. of gas which permits a good precipitation on gas without conditioning is given from tests made on a large installation.

The theory of back ionization and phenomena of discontinuous dielectric are discussed.

Electrical matters are shown to be secondary to treater design and to the conditioning gas. All that can be expected of electrical equipment is to stress the space between electrodes to the economical limit. Local conditions must govern choice of electrical equipment.

The tendency to regard electrical phenomena, such as surging which as a rule accompanies poor precipitation as causes rather than effects, is cited. Effects of conditioning gas in reducing surges is shown.

Internal reactance in transformer best suited to precipitation work is discussed, also possibility of exceeding the practical limit and wasting power on treatable gas by carrying voltage up to the point of disruption; necessity of knowing electrical values in the treater, and these are best obtained with milliammeter and electrostatic voltmeter; finally, the subject of proportioning the plant investment between electrical equipment and treater is covered.

CONTENTS

Introduction

In presenting this paper on the application of this process to smelter gases it is with the view of lending practical assistance to the engineer engaged in the smelting industry and furnishing useful information to others interested in the process.

The subject will be covered from the viewpoint of the engineer whose watchword must always be "return on the investment" rather than that of the physicist. However, consideration will be given to such theoretical matters as seem to have a practical bearing.

For the information of those not familiar with the metallurgy of copper and lead a short review will be made of that portion of the subject affecting the adaptation of the Cottrel process.

The present scope and diversified applications of the process preclude a complete discussion in this paper, but the general principles are sufficiently covered to insure an understanding of their application to smelter gases. The essentials are stressed and the non-essentials pointed out. Among the things featured are economy of treater design and methods of treating gases carrying solids difficult to precipitate, the solution of which will materially extend the scope of the process in the metallurgical field.

Presented at the Pacific Coast Convention of the A. I. E. E., Vancouver, B. C., August 8-11, 1922.

Description

The process which the genius and foresightedness of Dr. F. G. Cottrell gave to the world in 1908, out of what had been previously considered an interesting phenomenon, is essentially as follows:

A gas, or air stream, carrying solids or liquids in suspension, is subjected to the influence of a strong electric field produced by unidirectional current of high potential for the purpose of charging these particles and throwing them out of the gas stream. The gas is passed through the space between suitable electrodes and this space is made part of a high-potential circuit by placing it in series with the high-potential winding of a step-up transformer. Rectification is accomplished by a revolving switch, driven in synchronism, in series with the electrodes and high-potential winding of the transformer. The current is pul-

sating in character, but this is only incidental as the same results of precipitation may be produced by any source of high potential direct current.

The electrodes are usually referred to as "passive" and "active" since only the cathode serves as a charging electrode. This is effected by making it of relatively small surface compared with the anode so as to make a steep potential gradient near its surface. The passive electrode with its relatively large surface serves as the principle collecting electrode because most of the dust is driven to it. For purposes of safety the anode is made the grounded side of the system.

A few words as to the commonly accepted theoretical conception concerning the manner in which the dust particle is charged and precipitated: This is accomplished through the ionization of the gas which carries the particles in suspension. It is assumed that the negative ion or electron is the ionizing agent and that the velocity of the electron stream is sufficient to ionize the gas molecules by collision in a relatively small zone near the discharge electrode where the potential gradient is steepest. This stream of electrons in making its way toward the opposite electrode is assumed to charge the minute dust particles in passing by contacting or attaching to the particles. The latter having acquired a negative charge, and being in a strong electrostatic field, are attracted by the positive pole and hurled against it with considerable force, where they give up their negative charge to this electrode and cling to it by adhesion.

There are many iinteresting speculations, such as the possibility of some of the particles being charged by electrostatic induction; the effect of the electric wind caused by the electron stream, in aiding precipitation, and the indication and that some of the particles must be charged positively on account of the deposit which is always found on the discharge electrode; but these things are beyond the scope of the paper.

We need not be concerned with the phenomena of just how the particle is charged, but we are with how it may be enabled to give up its charge to the electrodes under all conditions. The inability of the charge to penetrate the insulating coat of dry precipitated fume causes precipitation to cease just as an insulating diaphragm does when placed between the anode and the cathode in an electrolytic cell. The problem in metallurgical work is to overcome this difficulty.

Application of the Process to Smelting

In its application to the smelting industry the process differs from other applications in several ways, but especially in the matter of size. Installations are as a rule, based on treating from 100,000 to 1,000,000 cu. ft. per minute. Other installations treating 25,000 cu. ft. per minute, such as at brass foundries and detinning plants, are considered a good size. Another important difference is the varying conductivity of smelter gas as compared with other gases. The matter so precipitated varies from a dry basic fume or dust to one containing enough dilute sulphuric acid to make it difficult to remove the deposit from the electrodes.

Electric precipitation was used primarily for the purpose of abating a nuisance by preventing solids from the smelter stacks being carried to the surrounding fields. A greater usefulness was soon found for it in recovering these solids for the values therein.

Twenty-five years ago in the copper smelting industry comparatively little attention was paid to recovering the solids driven off with the gases from the furnaces. The first attempt was made by building longer flue chambers to recover what might be settled out by gravitation and by adherence to the walls. As the industry increased more attention was paid to the very considerable dust losses and these flues were widened considerably for a length of 100 ft. or more to reduce the gas velocity, thereby causing considerable of the heavier suspended solids to drop out. During this time, and in fact prior to it, the system of filtering the gas through woolen bags for the purpose of reclaiming these solids, was in use in lead smelting. This method could not be applied very well to copper smelting due to the fact that the gases were much hotter and usually carried considerable sulphuric acid, these conditions contributing to the rapid deterioration of the bags. At one copper smelter, however, a bag-house was successfully operated by causing the heat from the gases to radiate from a long series of iron pipes, all the free acid being neutralized before reaching the bags by the large amount of zinc oxide present.

The principal disadvantages of bag-houses are the high first cost, together with the maintenance cost of bag renewals, and the very considerable cost of power rquired for forcing the gases through the bags and for producing mechanical draft.

While the long brick settling chambers were quite expensive, especially if equipped with hoppers, they constituted the only practical method of reclaiming the dust lost from copper smelters until the advent of the Cottrell process. Even then it was for a long time considered only an adjunct to the settling chamber. Until recently many of those best informed considered that the process was applicable exclusively to the field where the gases carried enough sulphuric acid, due to the sulphur in the charge, to render them conductive, and that all dry gases could be treated only by the bag-house. As will be shown later, the process is now being extended to dry gases also, by means of conditioning such gases.

Although quite expensive when constructed of steel pipes with hoppers and header flues, the Cottrell plant proved to be a very good investment on account of the large amount of solids recovered which would not settle out by gravity. One serious drawback to this type of treater, which limited its application, was the inevitable loss of draft, partly due to cooling the gases in passing through these pipes but principally due to

the loss in velocity head in passing the gas around so many extra right-angle bends.

Due to recent improvements in treater design smelter construction has been revolutionized by the Cottrell process. Almost any kind of gas can now be treated and long settling chambers are no longer necessary. The chimney may be erected comparatively close to the furnaces and connected with them by a short length of chamber equipped with electrodes which recover all that the long chambers formerly caught plus the larger amount which passed them. This can be done with practically no loss in draft.

Treater Design

The original treater consisted of a tank through which the gas was passed horizontally. The positive electrodes consisted of narrow lead plates placed vertically and edgewise to the gas current. Adjacent rows were staggered with reference to each other. Midway between each pair of plates and insulated from them were hung the negative discharge electrodes, which consisted of lead rods to which were clamped strips of micanite with saw-tooth edges. Later iron was used for both sets of electrodes where the gas to be treated carried little acid.

The pipe treater was developed in 1911 and has been used extensively since. In this treater the gas is by-passed from the main flue through vertical iron pipes from 10 to 15 ft. long and then returned to the flue where it passes on out the chimney. Iron wires of about No. 14 gage, supported by an insulated frame, are stretched through the axis of these pipes and serve as negative or discharge electrodes. Most of the dust is precipitated on the inner surface of the pipes and is shaken from them nto the hopper below by rapping the pipes after the flow of gas through them has been interrupted.

Somewhat similar to this in principal is the box treater, in which the pipes were replaced by vertical corrugated iron walls horizontal to the gas flow. Vertical chains or wires were suspended between these walls and were insulated in a similar manner as in the pipe treater.

The idea of using the corrugated iron walls was later used to better advantage by causing the gas to flow between them horizontally instead of vertically. This permitted installing them in a settling chamber already erected, and being a straight-line treater, the walls could be carried any desired length, whereas in the box treater the height of the walls was limited for structural reasons. In this installation the discharge electrodes consisted of $3/8$-in. iron pipes suspended parallel to the gas flow midway between the walls. Such a large surface does not permit steep enough potential gradient for the efficient ionization of the gas.

A short time previous to the development of the straight-line treater just discussed another type of straight-line treater was developed, which is known as the "screen treater." The object desired in this treater is to apply the principal of ionizing the gas in the most efficient manner and thereby reduce the power consumed, which is the principal fixed cost of a large plant. Probably more important than this to the plant manager is the very considerable reduction in first cost on account of the fact that chambers already in existence can be utilized and that in its construction a minimum of material and labor are required. Since these things have been accomplished so successfully on a large scale both in this type and in its successor known as the "wire treater," which is really a simplified screen treater, it seems worthy of some discussion from theoretical and practical standpoints.

In the pipe treater and various kinds of plate treaters, it is evident that the potential gradient is steep enough to ionize the gas only in a comparatively small area near the surface of the discharge electrode permitting a path of relatively large area near the walls of the pipe or plates through which the gas can flow in a straight line in a very weak electric field. In one large pipe treater installation in order to obviate this difficulty and get as high a degree of cleaning of the gas as possible, the gas was passed through three separate plants in series, the mixing action in passing from one plant to the other serving to give all the gas a better chance of being ionized. It was not practicable to increase the length of the pipes in one plant sufficiently to accomplish the same result on account of the amplitude of the swing of the discharge wires in the pipes becoming too great, due to the corona discharge. While this arrangement proved successful it was quite expensive from operating and first cost standpoints. It is quite evident that the same result as obtained with treaters in series can be obtained by putting vertically hung electrodes in series in the same chamber and having the gas flow parallel to the electrostatic discharge instead of at right angles to it as it does in all other types. In order to accomplish this in the best manner the gas must flow through the planes of the passive electrode instead of between them, which is only possible if the passive electrode is in the nature of a screen. Accordingly the treater was constructed by placing a series of parallel screens across a chamber. The discharge electrode consisted of vertical wires supported by an insulated structure and stretched between the pairs of screens. It is evident that these pairs of screens with their discharge wires function as treaters in series. Since the wires in each row are staggered with reference to the other rows, no single gas molecule can find its way through even a short series of these screens without passing close to a discharge wire and through a field sufficiently intense for its ionization. The reason for the relatively small cost of such an arrangement is obvious and requires no discussion. As to its economy of power used, this may be better understood by comparing a screen treater with any other type, say a pipe treater, each having its electrode surfaces proportioned so that the same

watts will be consumed in the two treaters, discharging in air. With the same volume of gas flowing through each, but an excess over the current amount, it is evident that the screen treater will precipitate the most dust on account of the more efficient ionizing of the gas for the power expended; therefore there are less watts consumed per unit weight of dust recovered. Having a minimum amount of surface exposed where radiation can take place, the temperature of the gas is conserved, and having no extra bends, the drop in draft is reduced to a minimum. The drop in draft across such a treater, cleaning gas at a 10-ft.-per-sec. velocity, rarely exceeds 0.1 inch of water and in no case has the precipitate on the screens interfered with operation, regardless of the sticky condition produced by acid. Draft is all important to the smelting man who finds more often than not, that a reduced draft means less ore tonnage smelted. Minimum draft loss is one of the features of this wire treater. Another important advantage is that there are no insulators exposed to the gas with the inevitable current leakage over their surfaces. The insulated structure is suspended at the four corners by members passing through holes in the cover plate. These holes are sealed by insulating lime seals in which crushed burnt lime, which has a high dielectric constant, acts so as to neutralize any acid which may condense on it and at the same time preserve a high dielectric strength. A feature worth noting is the fact that in this type of treater the gas stream always carries any dust that may be blown off toward a collecting electrode. Another advantage is the ease of shaking dust from a small or broken surface as compared to a solid surface.

The wire treater embodies all of the advantages of the screen treater plus the very distinct one of a greatly simplified construction with a much reduced first cost. In effect it amounts to electrifying a small portion of the wires formerly hung in a dust chamber for the purpose of knocking down the small amount of dust which might adhere to them mechanically. As in the screen treater, the length of the treater can be increased at will to obtain any desired degree of cleaning. The amount of dust caught over the length of the treater varies in the form of a logarithmic curve, half of the total being caught in a relatively short length making a very high return on the first portion of the investment. From this it is obvious that a large part of the solids in a gas can be recovered by installing a relatively short section of the treater, the length depending on the degree of clearance desired. In practise it has been found that a treater length of 20 ft. having an active or ionizing length of 10 ft. is sufficient to precipitate practically all the solids from gases flowing at the rate of from 10 to 12 ft. per second.

Metallurgical Considerations

In reference to the metallurgy of copper and lead, this paper is concerned principally with the conditions affecting the amount of water vapor and sulphuric acid in the gases from the various metallurgical units, and with the nature of the solids which the gases carry. It is on these things that the successful operation of the Cottrell plant depends.

As a rule these metals exist in their ores combined with sulphur, although there are some large oxide deposits. Before these ores can be smelted it is necessary to roast off a large amount of this sulphur. This is usually accomplished by multiple hearth roasters in which the ore is fed at the top hearth and is passed down through the succeeding hearths, being stirred or rabbled in transit. The sulphur in the ore usually furnishes the heat for its own roasting, although auxiliary heat is sometimes supplied. The gases from such roasters used for driving off excess sulphur contain more sulphuric acid than the gases from any other metallurgical unit. This acid is caused by the large amount of sulphur dioxide driven off and the fact that in passing up through the various hearths it has considerable contact with whatever catalysts may be present, such as iron oxide. The sulphur trioxide thus formed unites with the water vapor present in the gas and makes sulphuric acid.

There is another type of roaster in common use. It is a straight line roaster in which the fine ore is placed in thin beds on pallets which are drawn slowly through a short fire-box, this action serving to expel a large amount of the sulphur and at the same time to sinter or agglomerate the charge. The gas from this roaster contains very little acid on account of the short time of contact of the gas with the material at the proper temperature as it passes through the thin bed on the pallet. About the only thing contributing to making this gas treatable is the fact that in order to be agglomerated the charge must contain considerable water, often as much as 10 per cent. This water then furnishes enough conductivity to afford precipitation if the temperature is low enough to permit sufficient relative humidity to obtain.

In the case of copper, the roasted material, now known as "calcines", is then dumped into a large reverberatory furnace heated with powdered coal or oil. This type of furnace is quite similar to an open-hearth furnace, the gases leaving it being extremely hot. A large part of the sulphur remaining in the charge unites with the iron and copper in about equal parts to form a physical mixture known as "matte." This is separated from the slag by settling. The gas from this furnace contains very little SO_2 from which conversion to acid is obtained by coming into contact with whatever catalizer may be present on the side walls. In addition, the gas is very hot and there is practically no water in the charge, it being driven off by the roasting. These conditions make it an exceedingly difficult gas to treat.

Sometimes blast furnaces are used instead of reverberatory furnaces. This is often the case if the ore is in large lumps. The same disadvantages apply to

treating these gases with the added disadvantage of a wide temperature variation. This temperature variation depends largely on whether the furnaces happen to be operating with a cold or a hot top.

From the furnace the matte is poured into a converter, which is a relatively small cylindrical furnace, and is rotated on trunions for skimming off the slag. Air is forced in at the bottom and, passing up through the bath, oxidizes the sulphur combined with iron first, on account of the higher affinity of oxygen for such sulphur. Slag is produced by adding silica, and as it rises to the top is skimmed off periodically until only the combined sulphur and copper, known as "white metal" remains. During this slagging period very little acid is made which is available in the treater, and what acid is formed in the gases reacts with the oxides present, and the sulphates formed are not precipitated more readily than the oxides or sulphides of the original charge. The gas from a converter in the slagging stage is perhaps the most difficult of all to treat, as it contains no acid and practically all of the suspended solids are present in the form of fume, that is, material which has been condensed from a volatile state. During the second stage of converting, considerable acid is made due to the oxidizing of the sulphur, and conditions are favorable for good precipitation If there are several converters operating it is well to have their stages arranged so as to have at least one of them on the finishing stage all the time.

While the discussion has been confined principally to copper, the metallurgy of lead is so nearly similar that for our purpose little distinction need be made. It should be pointed out, however, that in lead smelting the reverberatory furnaces are not used, and that the lead is made without the use of converters it being smelted directly in the blast furnace where a reducing atmosphere is maintained.

The suspended solids from these various metallurgical units are sulphides, sulphates and oxides; however, the chemical nature of these solids does not seem to enter into the matter of their precipitation. Their physical nature is all important. It is a comparatively easy matter to precipitate flue dust, that is, material which has not been condensed from a volatile state. Frequently some of the material just as it is charged is present in the gas. This is especially true in the case of the multiple hearth roasters in which the constant stirring causes a considerable amount of the fine particles of the charge to be carried out with the gas currents. The wide application of the flotation process has contributed greatly to this dust loss from the charge, on account of the exceeding fineness of the particles. In fact, if it were not for the Cottrell process the flotation process would not be as great a success as it is, because of these losses.

There are several theories as to why fume does not readily lend itself to precipitation. Of these theories the one usually advanced is that on account of the exceedingly small mass of the particle it is not able to acquire enough electric charge, or enough momentum with the charge it does acquire, to cause it to lodge on a collecting electrode before it is swept by. This theory would seem to be disproved by the fact that these fume particles actually are charged and migrate to the electrode, but experience difficulty in giving up their charge to the electrode after the latter has become covered with a thin coating or film of such material. This is shown by the fact that if a practical method could be devised whereby this film is wiped from the electrodes every few minutes good operation would result. No method of shaking will remove this film sufficiently.

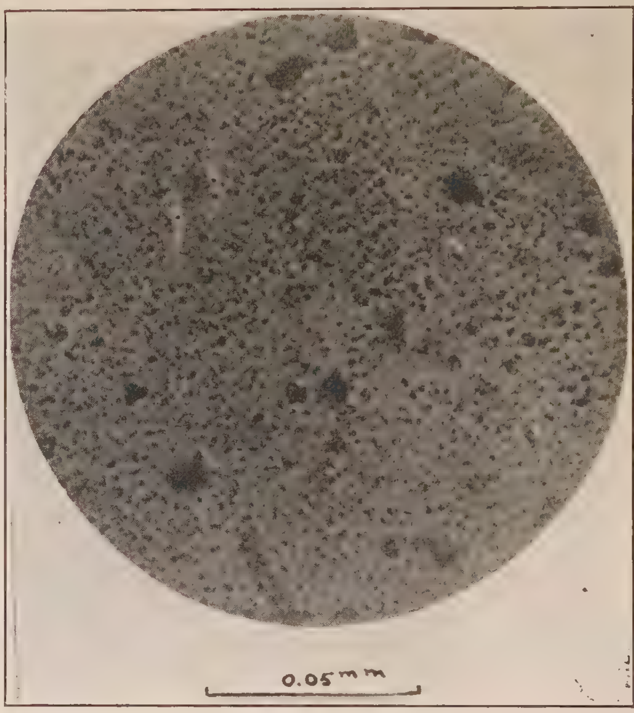

Fig. 1—Photo-micrograph of Converter Fume Magnified Approximately 560 Diameters
The dark grains are silhouettes of the particles.

There has been some speculation as to the effect of the air occluded in the fume on the electrode. It is a fact that if the fume shaken from the electrodes is beaten or squeezed, enough air will be excluded to make the fume occupy a very much smaller volume than before.

Another theory, which seems the most likely, is that the trouble is due almost entirely to the smooth amorphous state of this coating on the electrodes making it very compact, whereas the flue dust is of a porous nature having small interstices through which the charges may be forced. A good analogy of this is the insulating properties of various kinds of wood. It is known that pine is a relatively poor insulator for high voltages, whereas the same thickness of maple is exceedingly hard to puncture. The difference in

the dielectric strength of these two woods is probably due largely to the difference in porosity. A point lending color to this theory is the fact that if flue dust or other rather coarse material is mixed in with the gas and precipitated with the fume it improves the precipitation of the fume.

Fig. 2—Photo-micrograph of Roaster Flue Dust Magnified Approximately 560 Diameters
The dark spots are silhouettes of the particles.

The difference in physical structure between fume and flue dust is shown clearly by the photo-micrographs submitted. Figs. 1 and 2 show the particles silhouetted on glass mounts, consequently the dark spots are the grains. Fig. 1 shows the fume particles of high lead content from copper converters which must be conditioned previous to recovery in a Cottrell plant. Fig. 2 shows fine flue dust recovered from roasters which lends itself to treatment very well without conditioning in spite of the fact that it has a very high dielectric strength. This dust without magnification appears to be a dark powder of fineness comparable to that of the fume but when the two are magnified approximately 560 diameters, as shown, each particle of flue dust is shown to be about 20 times larger than the fume particle. These flue dust particles are also shown to be irregular in form with rough edges from which an electric charge can readily leak and pass through the interstices of the coating to the electrode. These sharp edges are further indicated by the wavy lines which are pictures of minute spectra caused by fine edges, similar to diffraction gratings, or crystal clevage planes. The fume particles are seen to be almost spherical in form which fact would make the particle tend to hold its charge.

In Figs. 3, 4, and 5 are shown the compact surfaces of converter fume, roaster flue dust and blast furnace flue dust, just as they were taken from the treaters without any attempt to compress them. The compactness of the fume as shown by its enamel amorphous surface as compared with the granular porous structure of the flue dust is clearly seen. The sample of blast furnace flue dust was taken at a time of excellent precipitation. Under high magnification it resembles a mass of coke. Fig. 6 is a photo-micrograph of chemically pure zinc-oxide which is a true fume and is submitted for purposes of comparison. Its general structure is seen to be quite similar to the converter fume. The areas photographed represent a magnification of approximately 43 diameters.

Laying aside theoretical considerations, the important point is a practical solution of the problem of conditioning gases and this will now be discussed.

Conditioning the Gas

By far the most important consideration in the operation of a plant is keeping the gas and the precipitated coat conductive. Conductivity is a relative term. What is considered a perfect insulator for ordinary voltages and currents may become an excellent conductor where only extremely small currents and high voltages are involved.

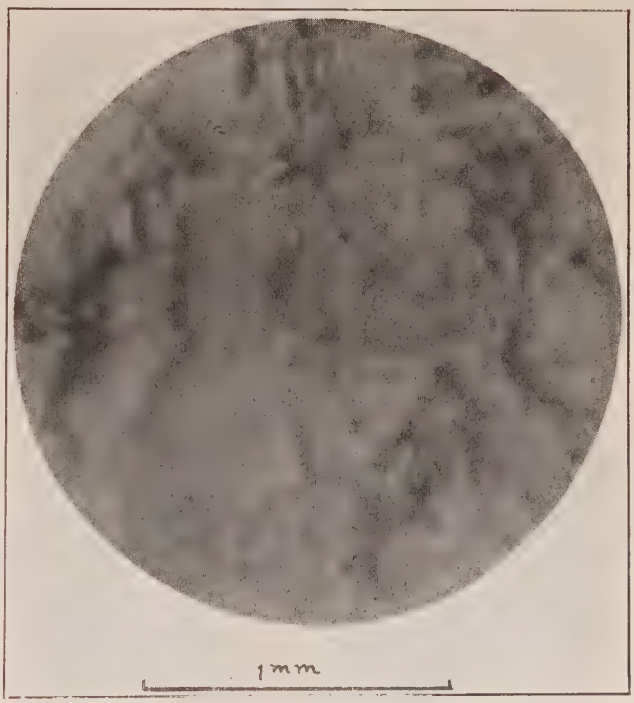

Fig. 3—Photo-micrograph of Surface of Converter Fume Magnified Approximately 43 Diameters

There are two ways in common use of supplying the necessary conductivity if it does not exist; the addition of sufficient aqueous vapor to the gases, or the addition of very fine acid particles. While the results obtained in each case are the same as regards furnishing

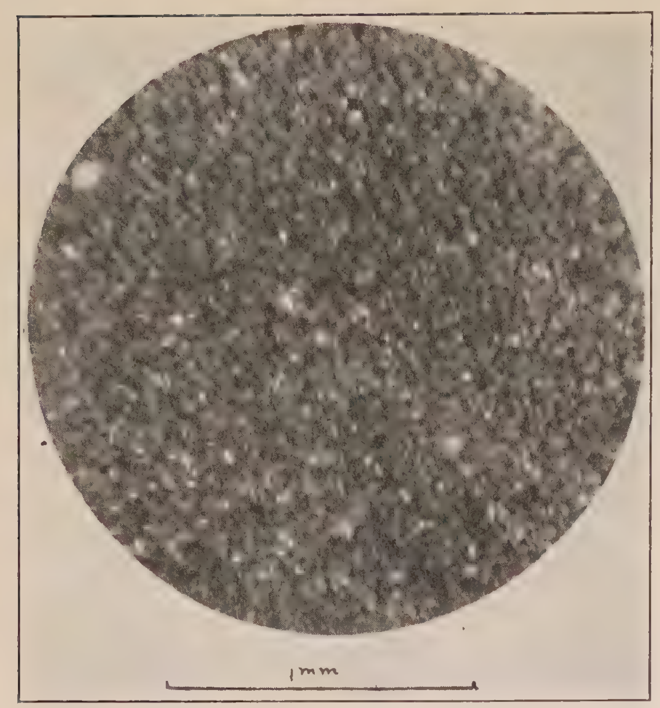

FIG. 4—PHOTO-MICROGRAPH OF SURFACE OF ROASTER FLUE DUST MAGNIFIED APPROXIMATELY 43 DIAMETERS

conductivity for the charge, their methods of functioning are somewhat different.

The selective adsorption theory as an explanation of how relative humidity functions in furnishing conductivity was advanced by the writer in a discussion of a paper presented to the Institute of Mining and

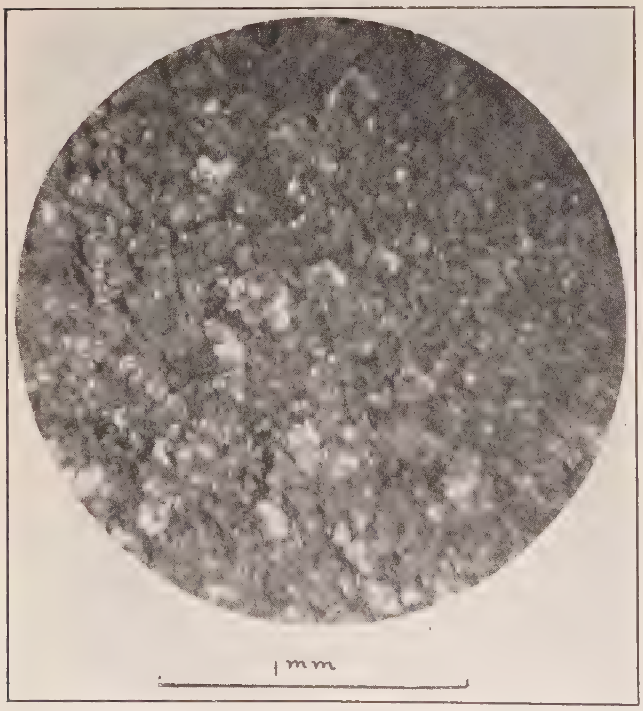

FIG. 5—PHOTO-MICROGRAPH OF SURFACE OF BLAST FURNACE FLUE DUST MAGNIFIED APPROXIMATELY 43 DIAMETERS

Metallurgical Engineers in 1919 by Mr. Eschholz on the subject of "Electrostatic Precipitation." It was pointed out that the dry dust particle must take on a film of moisture, for aqueous vapor is known to be taken up by the surface of solids, and that these adsorbed surface films persist at temperatures far above the boiling point of water. The early work of Bunsen in trying to remove the last traces of moisture from powdered glass or the interior of glass tubes was cited.

If the very slight surface adsorbed film is sufficient to conduct off the charge from the glass plates rendering an influence machine almost inoperative on a humid day, it is not hard to understand why the film adsorbed by dry dust particles from air or gas of like humidity should be sufficient to conduct a charge through the

FIG. 6—PHOTO-MICROGRAPH OF SURFACE OF CHEMICALLY PURE ZINC OXIDE SUBMITTED FOR COMPARISON

coating to the plate, since the current per unit area is of about the same order as that in the case of the influence machine. As evidence of this 50 milliamperes is a good average current for a treater of 200 pipes six inches in diameter and 12 ft. long. This gives a current density of 0.0135 milliamperes per square foot of electrode area at the pipe. This is to show that aside from the fact that it is a physical impossibility to precipitate droplets of water from a gas below the point of saturation, it is unnecessary, for the aqueous vapor alone is sufficient to conduct off the charge. It has been claimed that the relative humidity itself did not function in conducting away the charge but was only indicative of a condition whereby droplets of water could be precipitated.

Increasing the relative humidity of the gas is usually

accomplished by spraying into the gas a considerable quantity of finely atomized water by the use of suitable sprays at very high water pressure. Since the relative humidity increases faster and faster with a given moisture content as the temperature is lowered below the boiling point it follows that the water sprayed into the gas is more useful in raising the relative humidity due to its cooling effect than by virtue of the water added to the gas.

From a curve showing percentage by weight of water in saturated air, it is seen that at 100 deg. the percentage of water is only 0.14 per cent. At 120 deg. it is 1.07 per cent, rising with increasing rapidity so that at 150 deg. it is 6.34 per cent.

It is interesting to note that in a large installation operating on roaster gases the cooling effect of the gases during winter weather is sufficient to raise the relative humidity of the gas to a good working point due to the water in the furnace charge, although the latter is not changed in percentage.

As regards the limits for good operation, it was shown about five years ago that when the relative humidity of the gas was kept between 40 per cent and 70 per cent the precipitate would not be too dry or too wet for good work and all other connsiderations, such as temperature could be neglected since the temperature factor is reflected in the relative humidity. This reduced the field that could be covered by water treatment to comparatively cold gases only. Two serious objections to this method quickly developed. It was found that the water caused rapid deterioration of the flue system at the sprays, and the humid gases caused corrosion of the steel of the treater due to condensation at points exposed to the influence of the outside air. Perhaps more important was the reduction of the effective draft due to the cooling of the gases. This in several instances reduced the tonnage smelted. In spite of these difficulties this method is still used to a large extent.

Mr. Wolcott[1] has offered some important theoretical considerations on this matter. In citing the well-known fact that the tendency to arc between a plate and a point is greater when the point is positive than when it is negative, he pointed out that experiments showed the arcing voltage was considerably lowered when the plate is covered by some insulating material. This he did by placing various substances on the plate capable of retaining a charge, such as a sheet of paper or mica. The arcing voltage was lowered still further by a hole in the sheet. A glow was seen to emanate from the edges of the hole. Roughening the surfaces had the same effect. Roaster dust containing a large amount of elemental sulphur, when it was sprinkled on the plate, acted in the same manner. In every case these effects disappear when the dielectric on the plate was dampened very slightly or when the atmosphere was quite humid. He accounts for this glow, which under some conditions can be seen in the dark on the passive electrode, by theory of back ionization, and to the phenomenon produced by discontinuous unlike dielectrics in series which in this case are the dust particles in the coat and air in the interstices between them. The charge, which is retained by these particles, is evidently sufficient to ionize the gas adjacent to them. Since the sign of this charge is negative like that on the particles migrating to the passive electrode, the latter will be repelled, somewhat, by the dust already precipitated.

It seems, however, that these phenomena are results of precipitation having ceased, and not the causes. It is evident that the moment the particles can no longer give up their charge it becomes equivalent to an open circuit. We may be concerned more with another result of this back ionization than we are with the lowering of the sparking voltage. The redistribution of the potential gradient, due to the ionization which starts somewhere in the interior of the coat near the surface of the electrode, unquestionably lowers the gradient at the discharge electrode by the amount gained by the passive electrode. In this way it differs from the ideal distribution of the voltage, in which its gradient is as steep as possible near the surface of the discharge electrode, and quite flat at the passive. This is similar to a case cited by Dr. Whitehead in which he found that the corona glow at the wire almost disappeared when an intermediate concentric tube was inserted between it and the outer tube due to the accumulation of ions in the intermediate tube lowering the gradient at the wire.[2]

The method of conditioning with sulphuric acid is much more important than conditioning with water since it extends the scope of the process to dry gases well above the boiling point of water without any material lowering of the temperature and draft. This is due to three of its properties; its relatively high boiling point; its power to absorb water from surrounding gases at temperatures well above the boiling point of water; and to its rapid rate of diffusion over the surface of solids.

Since it remains in a liquid form at ordinary gas temperatures it is evident that the phenomena of selective surface adsorption does not occur as it does in the case of the aqueous vapor. It is more likely that it furnishes its conductivity by being precipitated as minute acid droplets which are well disseminated through the precipitated coating and quickly spreads a film of acid over the surface of adjacent dust particles due to its high rate of diffusion. Probably it is for these reasons that it has been found absolutely necessary to get a high degree of atomization of the acid.

There are several methods of introducing the sulphuric acid into the gases. Of these probably the

1. "Effects of Dielectrics on Sparking Voltage," by E. R. Wolcott, *Physical Review*, N. S. Vol. XII, No. 4, Oct. 1918.

2. "Electric Strength of Air," Whitehead and Brown, A. I. E. E. Transactions, Vol. 36, 1917.

better is to fume it off by boiling the acid and introducing the mist into the gases at some point in the flue system where it may become well mixed through the gases before reaching the treater. In one instance the intense heat of the copper converters was taken advantage of for the purpose of conditioning the gases, by introducing the acid at the hood of the converter by means of a spray. The intense heat atomizes the acid to the highest degree. The advantages of this fine dissemination of the acid probably more than offsets the disadvantage caused by cooling the gases from approximately 1000 deg. cent at the converter hood to 150 deg. cent. at the treater, resulting in considerable acid lost in forming sulphates since time is afforded for the reaction at suitable temperatures.

Another method consists of breaking up the acid into a very fine mist by high pressure air sprays and introducing it at a point near the treater so that all of the acid may be available in a free state. One advantage of this method is due to the fact that it permits dilution of the acid before mixing with the gas when required. Concentrated sulphuric acid is a very poor conductor of electricity. It becomes more highly dissociated and hence more conductive electrically as it approaches a concentration of 30 per cent. It is hard to precipitate a very dry mist, such as that fumed off by boiling, unless it has an opportunity of diluting itself by coming in contact with air containing appreciable moisture. In cases where there is practically no moisture in the gas the acid introduced may all be made available in the treater by diluting it before spraying into the gases, at the same time furnishing a greater volume of liquid at a higher degree of conductivity with which to condition the particle. This result can not be obtained in boiling the dilute acid, for in this case the water is driven off first until the acid reaches a high concentration.

Another method of conditioning which conserves the acid is known as "conditioning the electrodes." Good precipitation may be secured from gases carrying a dry basic fume by spraying the interior of the pipe electrodes with a fine mist of sulphuric acid intermittently. The periods between applications vary from one to twenty-four hours, depending on the nature and amount of suspended solids. If there is present much zinc oxide or other material which will quickly take up the acid, more frequent applications are necessary. It seems that the acid sprayed on the walls of the pipe adheres to them absorbing water from the gases, spreading a conductive film over the solids as they are precipitated until the supply is exhausted. Better results are obtained when the inner pipe surface is almost imperceptibly dampened with the mist than when it is thoroughly wetted.

Since the success of precipitation in smelter gases depends largely on the sulphuric acid content of the latter it may be interesting to note just what constitutes the right amount for good working conditions. Data were taken over a considerable period of time to establish this during the operation of a plant securing good results without conditioning the gases. With an average gas volume entering the treater of 470,000 cubic feet per minute at 184 deg. cent. of mixed converter, roaster and furnace gases, the precipitation over the period as noted visually varied from poor to excellent with the sulphuric acid content of the gases, and filtration tests showing that 67.7 per cent of the solids entering the plant over the entire period had been recovered. The average SO_3 entering the treater during this period was 4.9 g. per 1000 cu. ft. of gas (standard conditions), which is equivalent to 6 g. of H_2SO_4. Leaving the treater, there were 3.1 g. SO_3 or 4 g. H_2SO_4, showing that 33 per cent of the acid was precipitated. This gave a free acid content in the dust precipitated of around 1 per cent. A good working rule is, that gas lends itself to treatment readily if it contains enough acid to give a free acid content in the dust recovered of from 1 per cent to 5 per cent. With greater acidity the dust becomes sticky making it difficult to remove the precipitate. It also causes a high treater current and low treater voltage, which means high power consumption with poor precipitation.

Electrical Considerations

There was an early tendency to attribute the frequent fluctuations or erratic behavior of the plant to various electrical phenomena, especially when it was repeatedly seen to accompany poor precipitation. An example of this is when the dryness of the precipitate on the electrodes increases the electrostatic capacity of the treater sufficiently to cause a resonant condition which is manifest in sparking across the protective gap between the terminals of the high potential winding of the transformer. This critical combination is possible since the capacity reactance of the treater is in series with the inductive reactance of the transformer during a portion of each cycle. That the low treater voltage that this necessitates in an effect and not a cause of the poor precipitation, is shown by the fact that when the electrical system is rebalanced by juggling the inductive reactance of the system so that the treater voltage can be forced up to its value for good work, poor clearing of the gases still continues. When the gases are humidified sufficiently the surging condition disappears and good precipitation results, which continues fairly good when the voltage is lowered down to where it was with the resonant condition. The good precipitation was the result of conditioning the dust particle so that it could give up its charge rather than to reducing the surges. The effect of humidifying the gases in reducing the surges is shown quite clearly by the oscillograms in Fig. 7, where the transient in the high-potential wave at the point the contact is broken is seen when the gases were dry to be about three quarters the root-

mean-square value. When they were humidified, this surge is seen to be greatly reduced. During this test, only one half of each wave was utilized for purposes of safety to the oscillograph. It is interesting to note in this connection that lowering the frequency of the impulses in the treater one-half in this manner has no effect on precipitation except as it lowers the resulting treater potential, and this can be partly compensated for by raising the primary voltage a corresponding amount. There are conditions where the power consumption can be cut almost in half in this manner with only a slight diminution in precipitation. As a rule though the values in the dust lost in this way more than offsets the cost of the extra power.

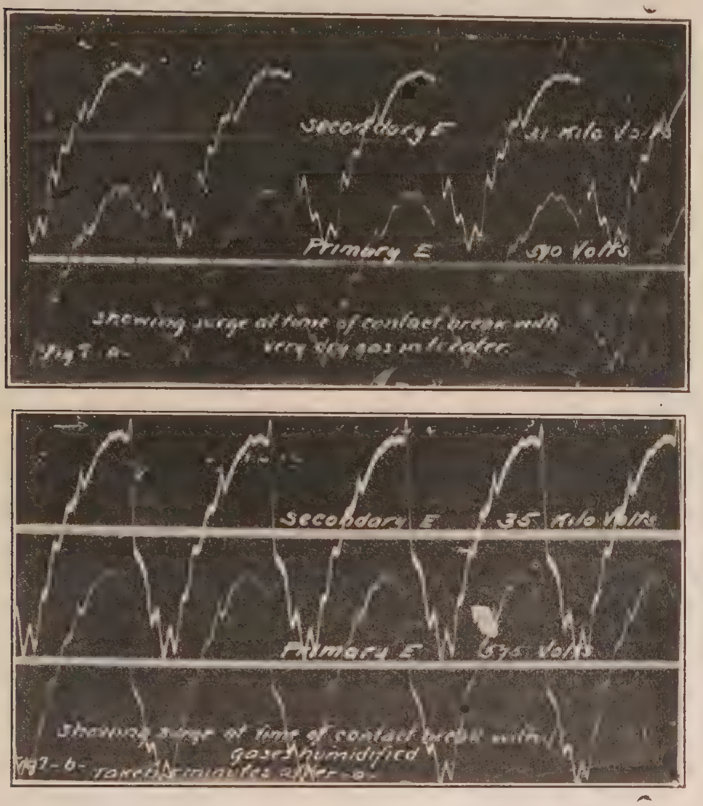

Fig. 7—Oscillograms Showing the Effect on the Surge in the High Potential Wave of Humidifying the Gases

Some of the early generators developed for precipitation work had rather a poor wave form, probably due to tooth ripples. These harmonics had a tendency to increase the effect of the surges and consequently this small defect frequently came in for a good share of the blame for poor work. As a matter of fact, when the gas is in good condition for treatment no difference can be observed in the precipitation from what it is with a perfect sine wave.

There has been considerable discussion as to the best transformer internal reactance. Off-hand one would say that a transformer of high internal reactance is best for the same reason that it is in electric furnace work, so that it can carry a short circuit, which frequently occurs in the treater, without injury. But this is not a real consideration since the revolving contact of the rectifier does not permit a very large current to flow into the treater even on short circuit. Standard power transformers have proved quite satisfactory. One reason for this seems to be that the greater the reactance the more the crest voltage of the wave will be lowered during the portion of the cycle that the rectifier connects the transformer to the treater, making a steeper wave front at time of contact and increasing the surging effects. This lowering of the crest voltage is shown by the oscillogram of the primary voltage wave in Fig. 8. The writer has frequently found that the tendency to surge was reduced by connecting to such a tap in the low-voltage winding as will give a maximum number of turns in series with a corresponding increase in the impressed voltage.

It is now pretty well understood that the electrical side of the process is of less importance than the treater and gas conditions. There is a saying among operating men "get the gas right and electrical troubles may be forgotten." That is the real problem. Electrical matters are relatively unimportant except as they effect the voltage and current of the treater. All that can be required of the electrical system is to stress up the space between electrodes to the economical limit, regardless of the source of the power, the number of electrical sets, or the type of electrical equipment comprising them. As to the current values, it is evident that with a given voltage impressed on the electrodes of a treater the current depends entirely on the conductivity of the space between electrodes and takes care of itself. At least there appears to be no method of varying it except to vary the conductivity of this space by changing the nature of the gas.

There has always been a good deal of uncertainty among engineers regarding the correct number of electrical sets to use for a given treater installation, or, putting it another way, the best proportioning of the investment. There has been a tendency to follow the lead of some other plant without determining if that proportion was best suited for their particular conditions.

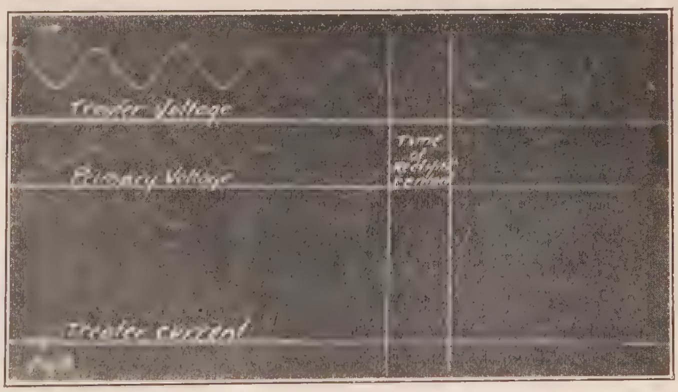

Fig. 8—Oscillogram showing the Time of Rectifier Contact to Primary Voltage Wave, the Treater Voltage Wave, and the Current Wave Impressed on the Treater

Since the main function of the electrical equipment is to keep adequate electrode potential, the investment for any equipment over this is wasted. The curve representing treater voltage, which may be taken as per cent precipitation as obtained from a single set, falls off rather fast beyond a certain limit as the number of electrodes is increased and then flattens out at about 50 per cent of maximum voltage. The problem is to determine the economical limit on this curve, *i e.*, to obtain the most satisfactory balance between the cost of extra machines and power consumed against the extra dust recovered. Since the values in the dust differ at different plants and the rate the treater voltage falls off differs with different types of precipitate, it is evident that no general rule can be laid down and that local conditions should govern. An economic limit for average conditions on a pipe treater was found to be

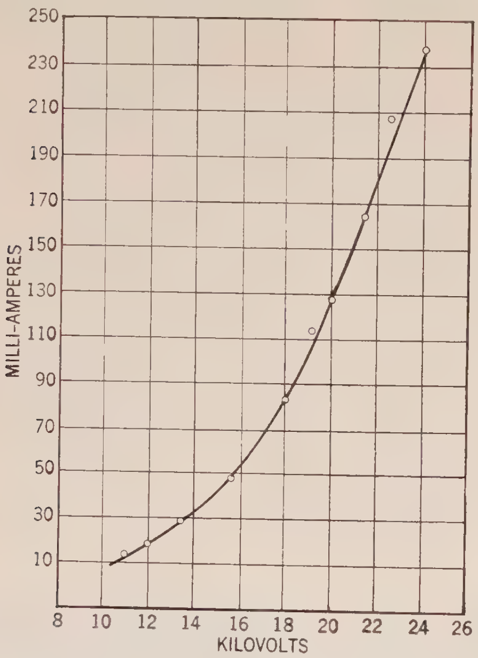

Fig. 9—Showing Current and Voltage Relations on Wire Treater as Voltage is Increased

200 pipes, 12 ft. long and 6 in. diameter per electrical set, but it should be pointed out that with the pipe treater the electrical set only comprises from 10 per cent to 15 per cent of the investment so that an increase of 25 per cent in the number of machines used did not add a large per cent to the total investment. A new complexion has been placed on this matter by the fact that in the more modern wire treaters the treater plant has been cheapened so much that the electrical investment is now as great as the treater investment, which has a tendency to increase the number of electrodes per set.

Electrical sets of 15 kw. capacity have come to be regarded as standard for precipitation work. This is due largely to the rectifier having a poor regulation. The drop in rectified voltage becomes considerable if it is attempted to pass much more than half an ampere over the revolving contacts of the rectifier. The transformer as a rule steps up from 440 volts to 22,000 and 44,000 with intermediate taps. This is suitable for the electrode spacing of six inches usually employed where an electrode potential of 25 kv. is adequate. However 12 in. spacing has been used somewhat, requiring voltage values of twice those given.

Mr. Eschholz has shown in his paper[3] that although the voltage is impressed on the treater in impulses, it has the effect of that from any continuous current source, due to the electrostatic capacity of the treater filling up the spaces between. This fact was established quite early by means of oscillograms (See Fig. 8 in which treater voltage and current waves are shown).

An important point not usually recognized is that due to the cumulative ionizing of the gases as the voltage is raised above a certain limit (explained by Townsends' theory of ionizing by collision) causes the circuit to become more and more conductive so that the last few thousand volts impressed on the electrodes is at the expense of greatly increasing the current flow and hence the power consumed. This is shown very clearly in Fig. 9. While this is a curve showing the current and voltage relations on a wire treater, it may be taken as typical of other types and follows very closely Mr. Peek's curve showing corona loss[4] near the critical voltage for large conductors. In the case in question it is seen that by increasing the voltage from 22 to 24 kv. the kilowatts consumed increased 43 per cent, a useless waste of power since the gases were cleared in this case almost completely at 22 kv. It is evident that considerable power may be wasted if the gases are in a good condition for treatment if the commonly accepted rule of carrying the treater voltage as high as possible is observed. This is a good rule to follow, however, if the gases are so non-conductive that adequate current cannot flow.

It is just as important to know the treater voltage and current values in a Cottrell treater as it is to know the cathode current density and cell potential in electrolytic work, and the best way of obtaining these is to connect a milliammeter in series with the ground side of the treater circuit and to connect a dead beat electrostatic voltmeter which reads root-mean-square values across the electrodes. While the readings obtained may be out a small percentage owing to the intermittent flow of current into the treater, they are at least comparable with each other and serve all practical purposes. It is misleading to try to calculate the treater voltage by multiplying the voltage across the low-tension winding by the ratio of the transformer, on account of the changing ratio of alternating current to direct current at the rectifier with varying conditions. It is

3. "Electrostatic Precipitation," O. H. E. Eschholz, Vol. LX, American Inst. Mining and Metallurgical Engineers *Transactions*.

4. "Dielectric Phenomena in High Voltage Engineering," F. W. Peek, page 144.

also often misleading to use the value of the current flowing in the low-tension winding at different times for comparative purposes, on account of the power factor changing with the nature of the gas in the treater.

As already intimated, the various types of electrical equipment used have received more than their share of consideration. For a time it seemed from the attention the matter received that the success of the process depended on whether the rectifying switch was driven by a small synchronous motor and the current impressed on the step-up transformer taken from the local power system, or whether it should be mounted on the shaft of a motor-generator, the current driving the motor being taken from the power mains and the single-phase current made by the generator impressed on the step-up transformer. In a discussion of Mr. Eschholz' paper already largely cited on this subject the writer pointed out that it was unfortunate that a non-essential should receive so much consideration and that it was really local conditions which should govern as to which system should be adopted, but pointed out a number of reasons why a large smelting company had found it expedient up to that time to install motor-generator rectifiers.

Acknowledgment is made of the cooperation and assistance of the Salt Lake Intermountain Experimental Station of the United States Bureau of Mines in connection with the photo-micrographic study of flue dust. Especial thanks is due Mr. R. E. Head for making the photo-micrographs, and to Mr. C. G. Maier for advice in their study.

An Arrangement of the Circle Diagram

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It is a well known fact that the Behrend-Heyland circle diagram for the "picturization" of the characteristics of the induction motor among all its advantages has a great draw-back, *viz:* its "space efficiency," if I may say so, being very low. We all know that the most important part of the diagram is confined to a small fraction of the diagram sheet, and that precision and convenience are very much hampered by this fact.

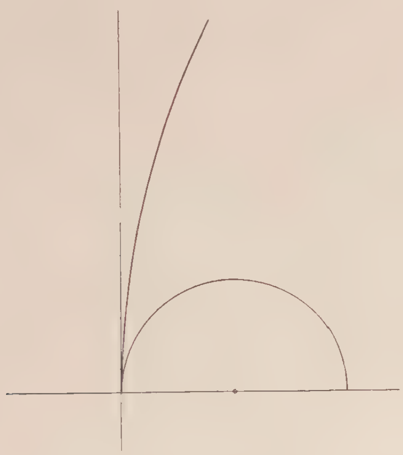

Fig. 1

The arrangement of the circle diagram described below aims to overcome this difficulty, also to bring about a more general survey of the effect of different winding conditions than is possible by the ordinary circle diagram.

The ordinary way of drawing the circle diagram is to fit the locus circle, varying for every special case, into an arbitrary, fixed co-ordinate system. The author's suggestion is to reverse this procedure, *viz: to make a variable co-ordinate system fit a constant locus circle.*

This conception makes possible "the standardized diagram sheet" which is an extra advantage of the method.

Fig. 1 shows the standardized diagram sheet containing a cross and two circle sections, the larger one having a diameter of for instance 100 cm. and the smaller one of 10 cm. It hardly needs explaining that the business of the larger circle is to get an enlarged view of the ordinary load conditions and that of the smaller circle to get the maximum load and torque values in a scale just sufficient to give the desired information.

The general characteristics of the induction motor besides by the no-load current are determined by the total inductive ohms L, the stator resistance r and the rotor resistance R (reduced to stator value)—all easily computed from the short-circuit test results. The diameter d of the locus circle is expressed in amperes by E/L where E denotes the phase voltage.

Suppose now that we standardize the size of d on the cross-section paper and make it D cm., and from reasons of proportionality it will follow that the measuring units of the cross section paper are determined by the following relationships:

$$1 \text{ cm.} = d/D \text{ amperes}$$

$$1 \text{ h. p.} = \text{const.} \times D/d \text{ cm.}$$

The value of the constant is, of course,

$$\frac{\text{watts per h. p. per phase}}{\text{phase volts}}$$

Proceeding, however, to Fig. 2, and with the constant

circles given, also knowing that $\tan \alpha = \frac{R + r}{L}$ we can start drawing the line $O - 5$, after which we draw $O - 1$ and $3 - 4$ in accordance with the values found for amperes and horse power. We have then,

$$\text{efficiency} = \frac{\text{length } 3 - 4}{\text{length } 2 - 4}$$

$$\text{power factor} = \frac{\text{length } 2 - 4}{\text{length } 1 - 4} \text{ etc. etc.}$$

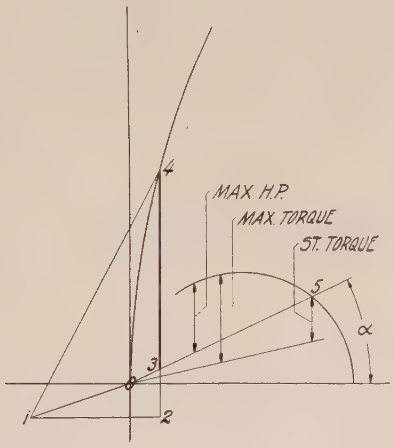

FIG. 2

The length $1 - 4$ representing the load current has to be translated into amperes from the value of the cross section unit, and in a similar way torque and overload values.

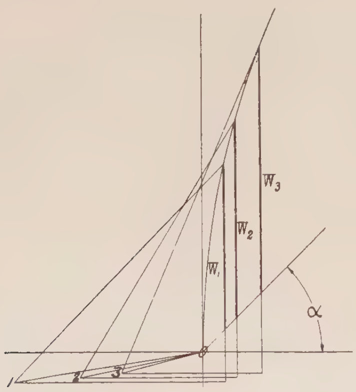

FIG. 3

It should be noted that as the locus circle and the no-load current are located on opposite sides of the coordinate axis, it is very convenient to make corrections for effects of the primary drop without a general disturbance of the whole geometrical construction.

While the above proceedings relate to the study of the characteristics of an individual machine, a slight consideration shows, however, that it is possible to use the arrangement for a general survey of all possible windings that could be applied to a given specification.

If in Fig. 2, the useful component (length $3 - 4$) is moved from the found location to some other place, retaining its original horse power signification, it means that the value of the measuring unit has changed and, therefore, the length of the circle diameter. Under otherwise unchanged conditions, this will mean *a changed number of turns of the stator winding.*

Fig. 3 shows a variation of the number of turns in the stator winding, keeping the copper volume constant. W_2 is the useful component of a certain horse power at a certain number of turns in the stator winding and the length $O - 2$ is the no-load current resulting from the winding in question.

Let, for instance, the number of turns of the stator winding increase 10 per cent, then the useful component moves to W_3 increasing its length by the squared value of the above increase or 21 per cent, at the same time as the no-load current moves to $O - 3$ (use the saturation curve for a 10 per cent lower value of voltage, and keep in mind the changed number of turns per pole, also the changed measuring scale).

A reduction of turns would be treated vice-versa (W_1 and length $O - 1$).

It should be noted that α does not change, because the resistance and inductance vary at the same rate under the above described conditions, (this corresponds to varying the voltage for a constant winding).

The changing measuring scale that we make use of in Fig. 3, does not, of course, affect proportions, so that the values of efficiency and power factor may be read off immediately for as many changed winding conditions as we care to investigate. This method is thus a very convenient way of finding the most favorable number of turns, be it in respect to efficiency or power factor.

I cannot, in this connection, refrain from drawing attention to the *rule of the varying measuring rod* which plays such an important role in the Einstein theory of relativity. Most of us may consider it an extremely unwelcome complication of the old honest Newtonian laws. We see here, however, how a complicated engineering problem is made extremely simple by applying the principle of the variation of the measuring unit.

In cooperation with the various states, the Bureau of Standards is investigating the proper illumination of registration plates on automobiles and the efficiency of various forms of tail lights.

This is an important matter, since the general subject of the color, position, etc., of tail lights is now receiving considerable attention throughout the country. The Bureau is also engaged on work covering automobile headlights with the idea of aiding in the unification of state laws governing these appliances.

The Action and Effect of Moisture in a Dielectric Field

BY DELAFIELD DU BOIS

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Review of the Subject.—*In studying the subject of dielectric loss in electric cables the author has become convinced that the moisture content of the dielectric is the dominant factor determining the a-c. resistance. Evershead's explanation of the action of moisture in a fibrous dielectric seems plausible but leads to the conclusion that moisture causes a decrease of a-c. resistance with increasing voltage, whereas the experience of the author is that with a fairly well dried dielectric a-c. resistance is independent of voltage, and that decreasing the moisture content still further gives higher and higher a-c. resistance, with no limit in sight. It seems obvious, therefore, that Evershead has not fully covered the subject. In order to get a picture of the action of moisture in a dielectric field the author has assumed a simply hypothetical case and tried to follow it to its logical conclusions. He assumed a pure dielectric of a homogeneous and plastic nature between parallel electrodes and subject to electric stress. He then mentally placed a very small globule of conducting moisture in the dielectric and watched the action. Under constant potential stress the moisture elongated into a thread-like filament until it bridged the dielectric. But under alternating stress the moisture globule, if sufficiently small stretched out only a short distance and then no further, no matter how high the voltage. This showed how the a-c. resistance could be independent of the voltage and yet depend upon moisture.*

Following up the analysis the author was surprised to find that such a dielectric, containing particles of moisture would show absorption and residual charge and many other characteristics of actual insulation. He also found that certain unusual test data, obtained while testing cables, could be explained as due to a breaking up of the moisture filaments by evaporation. The author does not claim that the paper that follows meets the complexity of actual insulation, but rather that it adds to our conception of the importance of moisture in its effect upon a dielectric field.

CONTENTS

THE phenomena observed when investigating and testing insulation can be classified into two groups. The first of these groups would comprise all the phenomena that a perfect insulator or pure dielectric would have. The second group would comprise all the phenomena of imperfection, such as leakage, dielectric loss, etc. In an attempt to account for the observed phenomena of this second group, it seemed advisable first to study a simple hypothetical case and to trace out the phenomena that might in that case be expected.

The case chosen was that of a pure dielectric between parallel plate electrodes and containing, embedded in it, minute particles of conducting moisture. The case was considered both with constant potential and alternating potential across the electrodes and with variations of voltage, temperature and frequency.

It is not claimed that the analysis that follows is complete, as a complete mathematical treatment would be extremely complex. The analysis shows, however, that a dielectric with many particles of moisture embedded would have all the characteristic phenomena actually found in insulation. The inference is, therefore, that all of these phenomena, of the second group, can be explained as due to the presence of moisture in the insulation.

Constant Potential Field

Consider first the forces that would act upon any single one of many particles of conducting moisture in a dielectric field with constant potential across the electrodes. Obviously if such a particle elongated into a filament of moisture, stretching in the direction of the dielectric field, it would reduce the energy of the field by shortening dielectric flux lines. It follows that a dielectric force would act upon the particle to

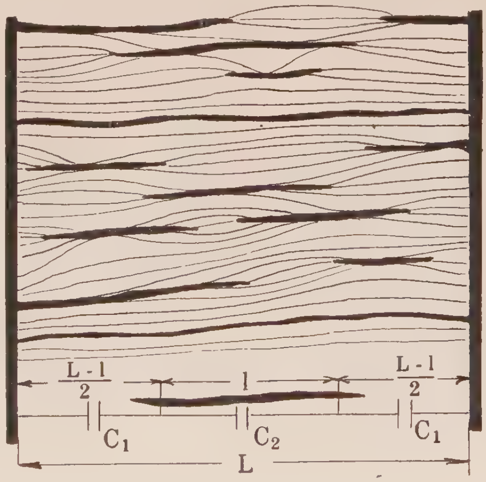

Fig. 1

produce such an elongation. We may designate this force as F_1

$$F_1 = \frac{E^2\, d\, C_1}{d\,(L - l)} \qquad (1)$$

where C_1 is the capacitance between an end of the filament and the nearest electrode and E_1 the voltage

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across this capacitance. L and l are the length of the dielectric and the length of the filament respectively, as shown in the diagram, Fig. 1.

C_1 and $\dfrac{d\,C_1}{d\,(L-l)}$ can hardly be expressed mathematically as they depend not only upon the dimensions of the single moisture particle or filament considered, but also upon the dimensions and arrangement of the other moisture particles and filaments in the dielectric.

As the filament elongated l would increase and C_1 would increase, increasing F_1, but as C_1, increased, and the filament included more and more lines of dielectric force, a current would flow through the filament and this current, flowing through the resistance of the filament, would produce a potential drop along the filament E_2. F_1 can therefore be expressed as

$$F_1 = (E - E_2/2)^2 \frac{d\,C_1}{d\,(L-l)} \tag{2}$$

E_2 would be a function of the rate of change of l with respect to time and also of the resistance of the filament. Since the volume of moisture does not change, we may assume for the resistance of the filament $R = \dfrac{l^2}{\gamma\,A}$ where γ represents the conductivity of the liquid and A the section of the filament when $l = 1$. A also is the volume of moisture of the particle. We may therefore write

$$E_2 = f_1\left(\frac{d\,l}{d\,t}\right) \times \frac{l^2}{\gamma\,A} \tag{3}$$

and

$$F_1 = \left(E - f_1\left(\frac{d\,l}{d\,t}\right)\frac{l^2}{2\,\gamma\,A}\right)^2 \frac{d\,C_1}{d\,(L-l)} \tag{4}$$

When current flowed through the filament, the drop of potential along the filament would set up a secondary field in the dielectric. This field would emanate from the filament exactly as magnetic lines of flux emanate from a straight bar magnet, and it would be nearly similar to the field that would be set up if the filament were replaced by two small electrodes in the dielectric, spaced a distance apart slightly less than the length of the filament and with a potential drop between them corresponding to the potential drop along the filament. The distance l may be considered as the distance that would separate such electrodes, and the capacitance of the secondary field C_2 would be the capacitance between such electrodes.

This secondary field would act to shorten the filament and the force of this field would be

$$F_2 = -\frac{E_2^2\,d\,C_2}{2\,d\,l} \tag{5}$$

or by equation (3)

$$F_2 = -\left(f_1\left(\frac{d\,l}{d\,t}\right) \times \frac{l^2}{\gamma\,A}\right)^2 \frac{d\,C_2}{2\,d\,l} \tag{6}$$

The actual dielectric field would at any instant be a resultant field of what are here called the primary and secondary fields.

As the filament elongated friction would act to retard the elongation. This force of friction would increase as the filament attenuated and would depend upon the section of the filament, upon the nature of the dielectric and upon the rate of flow; it can be expressed as

$$F_3 = -f_2\left(\frac{d\,l}{dt}\,l/A\right) \tag{7}$$

Surface tension would also act upon the filament to contract it. If we assume that the force of surface tension

$$F_4 = -K\frac{d\,s}{d\,l}$$

where S is the surface of the filament, we may write

$$F_4 = -K\frac{\sqrt{\pi\,A}}{\sqrt{l}} \tag{8}$$

Considering all of the above forces as acting upon the filament we can write, for an elongation $\dfrac{d\,l}{d\,t}$

$$\left(E - f_1\left(\frac{d\,l}{d\,t}\right)\frac{l^2}{2\,\gamma\,A}\right)^2 \frac{d\,C_1}{d\,(L-l)} - \left(f_1\left(\frac{d\,l}{d\,t}\right)\frac{l^2}{\gamma\,A}\right)^2 \frac{d\,C_2}{2\,d\,l} - f_2\left(\frac{d\,l}{d\,t}\,l/A\right) - \frac{K\sqrt{\pi\,A}}{\sqrt{l}} = 0 \tag{9}$$

The relation $\dfrac{d\,l}{d\,t}$ to the other factors is obviously very complex but certain useful relations can be deduced from this equation by inspection.

It is obvious that if either A or γ is increased $\dfrac{d\,l}{d\,t}$ will also increase. In other words a large particle of moisture will elongate more rapidly than a small one. A moisture particle containing more impurity will elongate more rapidly than one with less impurity, and, since conductivity increases with temperature, a hot moisture particle will elongate more rapidly than a cold one. It also seems to show that if A is small $\dfrac{d\,l}{d\,t}$ decreases rapidly as l increases.

Forces F_2 and F_3 tend to slow down the elongation but can not stop the filament from elongating. Force F_4 would decrease as l increased. It would seem then that no matter how small the filament became, it would ultimately bridge the dielectric—even if it became atomic in section.

When the filament finally bridged the dielectric, the forces F_1 and F_3 would disappear, but the filament

would now carry leakage current and would assume a gradient equal to the dielectric gradient. The dielectric field due to the potential drop along the filament would, therefore, remain, and the forces F_2 and F_4 would remain. These forces would hold the filament taut, but could not disrupt it or pull it away from the electrodes, for, if at any place along the filament the filament became thin, preparatory to a break, the resistance of that section would increase and the voltage gradient along that section would also increase. The resulting dielectric field would exert a force along the filament that would tend to flood the thin section in the filament with moisture from the thicker sections.

The filament would carry current electrolytically, that is, current would flow by migration of ions, and if the temperature of the liquid increased the velocity of migration would increase and possibly the degree of ionization would also increase. It follows that the leakage current would be greater if the dielectric were hot than if it were cold.

With current flowing in the filament, heat would be generated along the filament and this would increase the temperature of the filament and thus increase its conductivity. With increased conductivity the heat generated would increase and the temperature become still higher. This would result in a vicious circle, were it not for the fact that heat conduction to the surrounding dielectric would also increase with increasing difference of temperature between the filament and the dielectric, so that a condition of equilibrium would usually be reached. With a very small filament the ratio of heat generated to cooling surface would be small and such a filament would remain very close to dielectric temperature. Such a filament would show a resistance practically independent of the voltage between electrodes. If, however, the filament were large, we might expect resistance to decrease as voltage between electrodes increased.

If the temperature of the filament became sufficiently high, evaporation would occur, disrupting the filament. Evaporation might result in a general drying up of the filament, the moisture either leaving the dielectric or else forming a new filament or filaments in the dielectric adjacent to the original filament. Another possibility would be that the evaporation, being greatest at some one point, the resistance of that point would increase. The point would then become a hot spot and evaporation would further increase—a vicious circle ending in a local disrupture of the filament and a pushing apart of the sections by the resulting puff of vapor. This would decrease the flow of current and consequently the vapor would at once condense and the filament would be reunited, not only by the dielectric forces appearing across the gap in the filament, but also due to the vacuum when the vapor condensed. As soon as the sections of the filament united, in fact as soon as the ends touched, the action would be repeated—but the average conductivity would be reduced. With very large filaments evaporation might prevent any stable bridging of the dielectric.

The voltage at which evaporation first occurred would depend upon the size and conductivity of the filament. The larger the filament and the better its conductivity the lower the voltage of evaporation.

The voltage at which evaporation first occurred would also depend upon the temperature of the dielectric. The higher that temperature the lower would be the voltage of evaporation.

If a dielectric contained many particles of moisture, each of these particles would start elongating into filaments, but if the number of particles were great many of them would link up as they formed. This of course would decrease the time necessary to bridge the dielectric. Since, then, the time to bridge the dielectric depends both upon the number of particles and upon their size, it follows that the greater the moisture content of the dielectric the smaller the time required for the filaments to bridge the dielectric.

If a bridge were formed by the linking up of filaments as they elongated from particles of moisture of different sizes and conductivities, the voltage gradient across the bridge would not, at first, be uniform but the dielectric stresses set up along the filament, due to the gradient, would be greatest where the filament was highest in resistance. The result would be that an internal flow of moisture would occur until the gradient was uniform throughout.

If a dielectric containing many particles of moisture had voltage, from a source of constant potential, suddenly applied across the electrodes, the first rush of current would be the changing current of the dielectric. The maximum value of this current and its attenuation would depend upon the constants of the dielectric and the circuit and, if it were not for the moisture held by the dielectric, this current would soon drop to zero. However, as soon as voltage was applied, filaments of moisture would begin to form and, in forming, would apparently increase the capacitance of the dielectric by shortening the lines of force. The changing current would, therefore, persist beyond the normal time though gradually decreasing, as more and more of the filaments bridged the dielectric and the rate of change in length of others became less. But not until all of the filaments finally bridged the dielectric, would the changing current become zero. Leakage current would at first be zero but, as the filaments began bridging the dielectric, leakage current would increase. This increase in leakage current would at first be rapid, as the larger filaments and the filaments that linked up easily formed their bridges, but as the rate of bridging and the size of the filament that bridged became smaller and smaller the increase in leakage would become slower. Leakage would become maximum as changing current became zero. The action is shown diagrammatically in Fig. 2.

If the moisture content of the dielectric were great the action in building out filaments would be rapid and the leakage large. In that case as shown diagrammatically in Fig. 3 the current would reach its final value very soon after the application of voltage.

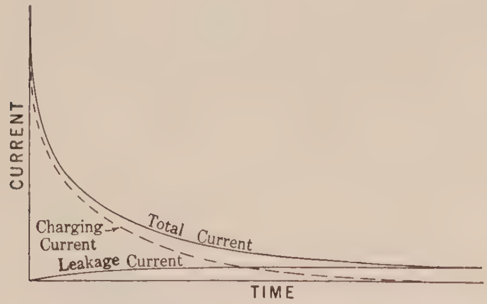

FIG. 2—"ABSORPTION" MOISTURE CONTENT SMALL

The phenomenon illustrated in Figs. 2 and 3 is apparently identical with what is usually called "absorption."

If a dielectric under electric stress, and bridged by filaments of moisture, were discharged by short circuit,

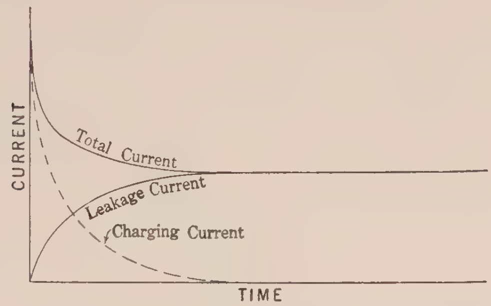

FIG. 3—"ABSORPTION" MOISTURE CONTENT LARGE

the primary field of force would disappear at a rate depending upon the resistance and inductance of the discharge circuit, but, as pointed out above, a filament carrying current would have established along it in the dielectric a secondary field, proportional to

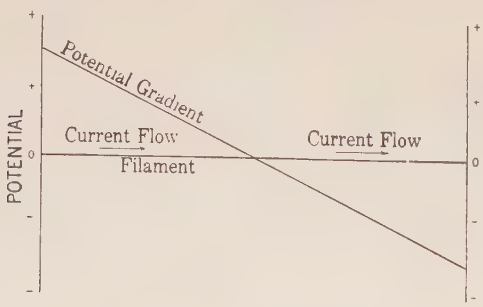

FIG. 4—NORMAL GRADIENT—DIELECTRIC CHARGED

the drop of potential along the filament. When the primary field disappeared this secondary field would become apparent and its discharge would be limited by the high resistance of the filament and, therefore, might be very slow. If Fig. 4 shows the normal gradient and flow of current along a filament under constant conditions in a changed dielectric field, the change in this gradient and current flow upon short-circuiting the electrodes would be as shown in Fig. 5.

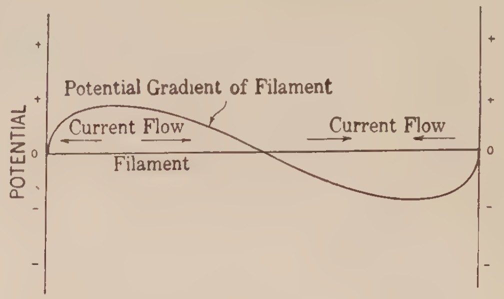

FIG. 5—FILAMENT GRADIENT—ELECTRODES SHORT-CIRCUITED

If left short-circuited long enough, the secondary field would become fully discharged and the gradient would disappear, but if, before that, the short circuit were removed the primary field would become reestablished

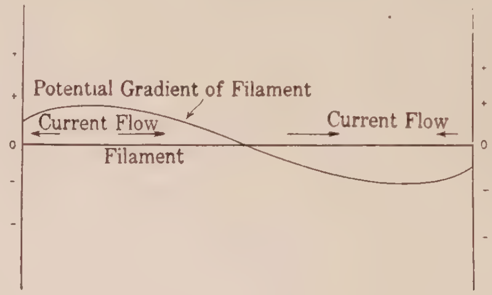

FIG. 6—SHORT CIRCUIT RMOVED—ELECTRODES RECHARGING FROM FILAMENT

by the secondary fields of all the filaments, as shown in Fig. 6 and 7.

The phenomenon illustrated in Figs. 4, 5, 6, and 7 is apparently identical with what is usually called "residual charge."

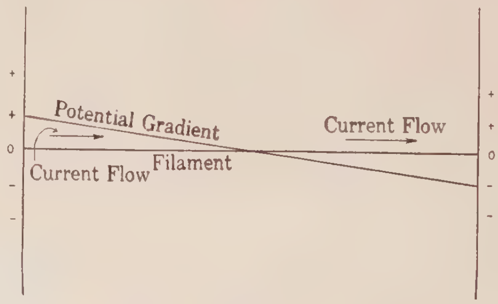

FIG. 7—"RESIDUAL CHARGE"

Discharge of the residual voltage would take place by leakage through the filaments until finally all difference of potential disappeared. When that occurred the force of surface tension would contract the filaments, but in contracting they would break up into small particles distributed along the paths of the filaments.

Alternating Field

As in the case of the constant-potential field already considered, particles of moisture embedded in an alternating dielectric field would be acted upon by four forces: F_1, a dielectric force acting to elongate them into filaments and due to the primary dielectric field; F_2, a contracting force due to secondary dielectric fields set up by the potential drop along a filaments; F_3, surface tension; F_4, friction.

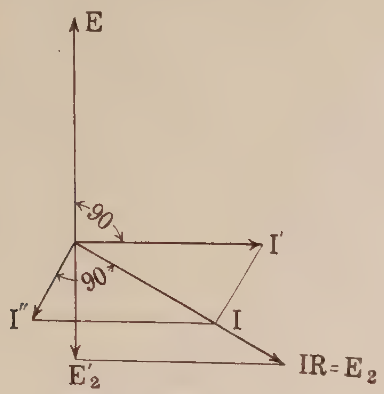

Fig. 8

The alternating field case is, however, rather more complicated than the other, because currents flow through the filaments whether the filaments are elongating or not. Thus, force F_2 is now not merely in the nature of a retarding force but acts to oppose force F_1 even if the filament is not elongating. Forces F_1 and F_2 are pulsating and not in phase.

To analyze the action, consider one filament of moisture, of many, in an alternating dielectric field. Alternating current I (see Fig. 8) would flow in the filament and this current can be considered as the resultant of two currents I' and I'', the first I' due directly to the main field, and proportional to the number of lines of force of that field entering the filament. This current would lead the electrode voltage E by 90 deg. I'', the second component of I is a current due to the secondary field set up in the dielectric by the voltage drop $I R$ along the filament. $I R$ is in phase with I and I'' leads this phase by 90 deg. It follows that E_2 leads E by more than 90 deg., and E_2 may be divided into two components, one of which E_2' is 180 deg. in phase from E. E_2', therefore, lessens the dielectric flux received by the filament and therefore lessens the force acting to elongate the filament. I of course, is proportional to the actual dielectric flux received.

The force F_1 would have a wave of double frequency and may be considered all positive. Its maximum values would occur when E was at full value either positive or negative. The force F_2 would also be of double frequency, and may be considered entirely negative. Its maximum values would occur when E_2 was at full value either positive or negative. The combination of these two forces would give a wave of force with both positive and negative values and with an intermediate phase. Due to friction, which in a small filament would be high, the filament could not respond to the rapid variation of the force cycles but would respond to the average resultant force F', of the force cycles of F_1 and F_2. If F' were positive in direction and exceeded the surface tension force F_3, the filament would continue to elongate, but elongation would cease if the forces F' and F_3 became equal and opposite in direction.

As the filament elongated its resistance would increase and, assuming that the total volume of moisture did not change, the resistance of the filament would increase in proportion to the square of its length. Although the current I might decrease as the filament lengthened, the voltage drop along the filament would be found to increase, and this would increase the force F_2. It would also swing the phase of the voltage E_2 further in advance of E and increase the component E_2' thus decreasing the force F_1. When the attenuation of the filament reached a certain degree the forces acting upon it would be in equilibrium and no further elongation would take place.

To show this a little more definitely it is convenient to consider the case from an energy standpoint, as all bodies, either conductors or insulators, in a dielectric field, tend to move or form themselves so as to take the max mum possible energy from the field. Thus if by elongating the energy loss in a filament would become greater, dielectric forces would tend to elongate the fi ament but the filament would not elongate if elongation meant a decrease of energy. The heat produced in the filament is a measure of the energy it takes from the field.

In Fig. 9, Let

$$1/r = g \qquad 2\,\pi\,f\,C_1 = b_1 \qquad 2\,\pi\,f\,C_2 = b_2$$

The admittance of the parallel circuit would be $y_2 = \sqrt{g^2 + b_2^2}$ and the impedance of the total circuit would be

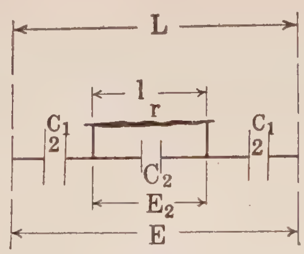

Fig. 9

$$z = \sqrt{\left(\frac{g}{g^2 + b_2^2}\right)^2 + \left(1/b_1 + \frac{b_2}{g^2 + b_2^2}\right)^2} \qquad (10)$$

It follows that since

$$E_2 = \frac{E_1}{y_2\,z}$$

and power loss in heating the filament $P = E_2^2\,g$

that
$$P = \frac{E^2 g}{\frac{g^2 + b_2^2}{b_1^2} + 2\,\frac{b_2}{b_1} + 1} \tag{11}$$

As the filament lengthened out and l increased g, b_1 and b_2 would change in value

$$g = \frac{A\,\gamma}{l^2}$$

where γ is the conductivity of the liquid and A the sectional area at unit length, which equals of course the volume of the liquid

$$\frac{d\,b_1}{d\,l} \quad \text{and} \quad \frac{d\,b_2}{d\,l}$$

are actually rather complicated functions of L and l; and b_1 does not increase as rapidly as $L - l$ decreases, nor does b_2 decrease as rapidly as l increases, but if a value of l can be found giving P a maximum value on the assumption of direct proportionality it may be inferred that at some shorter value of l the filament would attain its maximum length.

Assume therefore $\quad b_1 = \dfrac{B\,F}{L - l}$

and $\quad b_2 = B/l$

when B is the value of b_2 when the filament is of unit length and F a factor of proportionality between the two fields.

The equation can now be written

$$P = \frac{\frac{E^2\,A\,\gamma}{l^2}}{\frac{\frac{A^2\,\gamma^2}{l^4} + B^2/l^2}{\frac{B^2\,F^2}{(L-l)^2}} + 2\,\frac{B\,(L-l)}{l\,B\,F} + 1} \tag{12}$$

which reduces to

$$P = \frac{E^2\,B^2\,F^2\,\frac{l^2}{(L-l)^2}}{A\,\gamma + \frac{l^4\,B^2}{A\,\gamma}\left(1/l + \frac{F}{L-l}\right)^2} \tag{13}$$

If L is taken as unity, and l is small with respect to L this reduces to

$$P = \frac{E^2\,A\,\gamma\,B^2\,F^2}{\frac{A^2\,\gamma^2}{l^2} + B + 2\,F\,B\,l + B\,F^2\,l^2} \tag{14}$$

Differentiating this with respect to l and equating to zero gives

$$A^2\,\gamma^2 - F\,B\,l^3\,(1 + F\,l) = 0$$

F will not be a very large number and if l is small $\times\, l + F\,l$ can be considered unity and we may write

$$l_{max} = \left(\frac{A^2\,\gamma^2}{B\,F}\right)^{1/3} \tag{15}$$

Obviously for small values of l, $B\,F$ must be greater than $A^2\,\gamma^2$.

Now putting this value of l in equation (**14**) gives

$$P_{max} = \frac{E^2\,A\,\gamma\,B^2\,F^2}{3\,A^{2/3}\,\gamma^{2/3}\,B^{2/3} + B + B^{1/3}\,F^{4/3}\,A^{4/3}\,\gamma^{4/3}} \tag{16}$$

and if $B\,F$ is to be large with respect to $A^2\,\gamma^2$ the term B will dominate the denominator and we can approximate the above formula by

$$P_{max} = E^2\,A\,\gamma\,B\,F^2 \tag{17}$$

From equation (**15**) it is obvious that the length to which a filament would elongate is a function of the quantity of its moisture and of its conductivity. Presumably if the quantity of moisture were sufficient or its conductivity sufficiently high the filament would bridge the dielectric. It should also be noted that the length of the filament is, according to this equation, independent of voltage. This of course is not strictly the case, as the force of surface tension has been neglected. The equation (**15**) must therefore be considered as giving the limiting value of l when A is very small. Undoubtedly for small voltages the effect of surface tension would be apparent but as the voltage increased the dielectric forces would dominate, and if γ remained constant the length of the filament would not change appreciably with voltage changes.

Equation (**17**) is the approximate equation of dielectric loss due to the presence of a very short filament of moisture in the dielectric but for larger filaments equation (**17**) will not hold. Most likely as l increased the factor B should decrease in importance until for a filament of length such as to bridge the dielectric the factor B would disappear and the loss would be

$$P = E^2\,A\,\gamma \tag{18}$$

where $\dfrac{1}{A\,\gamma}$ expressed the actual resistance of the filament, since we assumed the dielectric thickness, L, to be unity.

If the dielectric contained many particles of moisture of various sizes, doubtless some would bridge the dielectric, some would not elongate beyond a limiting or short value and some in elongating would link up with others forming longer filaments of limited length or else would bridge the dielectric.

With some filaments bridging the dielectric and others of limited length the total dielectric loss can be expressed as

$$P = E^2\,\gamma \int_{l=0}^{l=L} A'\,B'\,d\,l \tag{19}$$

where A' is a function of A and l and expresses, for any length l, the total moisture in the dielectric, held as filaments, of length l, B' is a function of B and F with respect to l and varies from $B' = B\,F^2$ for very small values of l, to $B' = 1$ for $l = L$. B is also a function of l and would be 0 for $l = 0$. In this equation γ is as-

sumed to be the same in all filaments but if the filaments were of different temperature this would not be the case.

Dielectric Loss as a Function of Voltage

According to equation (**19**) the dielectric loss in a dielectric containing moisture increases as the square of the voltage indicating a constant "a-c. resistance" but as pointed out in the case of the constant potential field, the current flowing through the filaments generates heat, locally, and this may increase the temperature of the filaments, increasing the conductivity of the liquid of which they are formed, lengthening the filaments according to equation (**15**) and according to equation (**19**) increasing the loss. But, if the filaments are very small, radiation of heat to the surrounding dielectric would be rapid and might even cool the filaments down to the dielectric temperature between cycles. We would, therefore, expect that in a dielectric containing comparatively little moisture, dielectric loss would increase in proportion to the square of the voltage while in a comparatively moist dielectric the increase of dielectric loss with voltage would be at a greater rate. The phenomena of evaporation as explained in the case of the constant potential field would also occur in an alternating field and this might offset the increase in conductivity due to temperature rise as voltage increased. The evaporation, however, would only be apparent above some critical voltage. In other words, a dielectric containing moisture to such an extent as to increase in loss, as voltage increased, at a rate greater than proportional to the square of the voltage, would, above a certain voltage, show loss increasing at a rate more nearly proportional to the square of the voltage.

Dielectric Loss as a Function of Temperature

Assuming for the moment that the dielectric coefficient, k, is independent of temperature, then since γ, the conductivity of the liquid increases as temperature increases, it follows from equation (**19**) that the dielectric loss in a dielectric containing many particles of moisture would increase as the temperature of the dielectric increased. Furthermore as indicated by equation (**15**) an increase in γ would also cause a lengthening of all the filaments that did not already bridge the dielectric, and according to equation (**19**) this would cause a still greater increase of dielectric loss as temperature increased.

There seems, however, to be rather good evidence that the dielectric coefficient, k, is not a constant with respect to temperature. This will be brought out later, but assume for the moment that k decreases as temperature increases. B is proportional to k and so according to equation (**19**) a change in k will affect dielectric loss. In a comparatively dry dielectric a large part of the loss might occur in comparatively short filaments in which case the importance of B in the equation (**19**) for loss would be great. In such a dielectric the effect of the increase of conductivity as temperature increased might be somewhat offset by the decrease in k as temperature increased, though, as the filaments lengthened due to increasing temperature the importance of B as affecting loss would decrease. The result, in a very dry dielectric, might be that, when cold, dielectric loss would decrease as temperature increased but that, at a certain temperature, a point of minimum loss would be reached and that, for higher temperatures, loss would increase perhaps rapidly with temperature.

It has been stated above that dielectric loss is sometimes affected by evaporation, depending upon the moisture content and the voltage impressed. Another factor would be the dielectric temperature, for obviously if the dielectric were hot evaporation would occur at a lower voltage than if the dielectric were cold.

Dielectric Loss as a Function of Frequency

If a filament of moisture in a dielectric field were very short the importance of B as affecting dielectric loss would be great. B is proportional to frequency so the loss would be nearly proportional to frequency. If, on the other hand, the filament bridged the dielectric, the loss would be independent of frequency. In the case of many filaments of all sizes, dielectric loss would increase with frequency but in a degree depending upon the quantity of moisture and its distribution.

As an offset to the above is the fact that, as indicated in equation (**15**), the length of the filaments would decrease as frequency increased. This of course though tending to decrease dielectric loss would increase the importance of B and so increase the sensitiveness to changes in frequency.

With an increase of temperature, the variation of loss, due to changes in frequency, would be less as the increase of temperature would lengthen the filaments, and so give less importance to B.

Capacitance as a Function of Frequency

The capacitance of a dielectric containing embedded moisture elongated into conducting filaments would be greater than the capacitance of the same dielectric if no filaments were present, for although the effect upon the capacitance of such filaments as bridged the dielectric would be negligible, those filaments that partially bridged the dielectric would act to shorten the length of such lines of force as converged to them in crossing the dielectric. Thus the effect of these filaments would be the same as if the electrodes were moved nearer together. An increase in frequency would increase the factor B in equation (**15**) and shorten the length of these filaments; thus an increase in frequency should be accompanied by an apparent decrease in capacitance.

Capacitance as a Function of Temperature

As pointed out above, the effect of an increase of temperature upon the filaments that do not bridge the dielectric, is to increase their conductivity and

so increase their length. Obviously, this would increase the apparent capacity of the dielectric. But as stated above there is no reason to assume that the dielectric coefficient k is independent of temperature. It is a measure of the energy required to produce some atomic change, and the condition of an atom changes with temperature.

W. Grover[1] of the Bureau of Standards has found that the capacitance of paraffined paper condensers changes with temperature but with rather a complex relation to phase angle. It will be shown later that in the dielectric we are considering the larger the phase angle the greater the moisture content. Grover finds that, for a very small phase angle, the capacitance decreases as temperature increases—for a larger phase angle capacitance is nearly independent of temperature and for a still larger phase angle capacitance increases as temperature increases. A very small phase angle is equivalent to saying very few filaments and these of short length. Such filaments, although they would, presumably, increase in length as temperature increased, would, in lengthening increase the capacitance of the dielectric but slightly. If in this case the capacitance were found to decrease with an increasing temperature our only explanation seems to be that a decrease of k must have taken place. A larger phase angle would indicate more moisture, that is more filaments and longer filaments. When due to an increase of temperature, such filaments elongated, their effect upon capacitance would be more pronounced and might dominate over any change due to a change in k. It follows that when investigating k as a function of temperature, the moisture content should be as small as possible; in other words the phase angle should be small. In this case Grover found that capacitance decreased as temperature increased. The conclusion seems to be that the dielectric constant k actually does decrease as temperature increases.

Phase Difference and Power Factor as Functions of Voltage Temperature and Frequency

The phase angle of the changing current of a condenser would be

$$\tan^{-1}\theta = \frac{b}{g} = r_{ac}\, 2\,\pi\, f\, C$$

if however the phase angle is large we can assume for the power factor

$$\cos\theta = \frac{1}{r_{ac}\, 2\,\pi\, f\, C}$$

and since $r_{ac} = \dfrac{E^2}{P}$ $\quad \cos\theta = \dfrac{P}{E^2\, 2\,\pi\, f\, C}$

The term "phase difference" may be defined as 90 deg. $-\ \theta$.

1. The capacity and phase difference of paraffined paper condensers as functions of temperature and frequency. W. Grover, *Bulletin of the Bureau of Standards*, Vol. 7, No. 4, 1911.

The dielectric loss P and capacitance C have both been analyzed above as functions of voltage, temperature, frequency and moisture content, and as these are the only variables in the equation of power factor that would be influenced by moisture content it seems hardly necessary to fully develop their ratio. In general we might expect P to change more with moisture content and conductivity of the moisture than C and it would follow that in a comparatively dry dielectric, power factor would be lower and phase difference smaller than in a comparatively moist dielectric.

In any actual insulation the action of entrapped moisture would be more complex than in the simple case considered above. It is doubtful however if any usual insulation would be dense enough to prevent the penetration of filaments of moisture provided the filaments were sufficiently small, and they may of course be even atomic in section. The impossibility of freeing insulation from every trace of moisture is apparent when we consider the moisture content of the air. If we attempt to drive out moisture by high temperature we vaporize the moisture but even with vacuum we cannot get all of the vapor out. There seems to be an action of occlusion that holds to the moisture and brings in new moisture when possible from the air. If very high temperatures are used in drying, many insulations decompose and usually one of the products of decomposition is water.

The idea that moisture forms the conducting paths in insulation is not at all new, Evershead[2], by means of a very ingenious model studied the action of moisture as affecting the insulation resistance of fibrous insulating materials. This is of course a more complex case than the simple one considered above, since the fibers of the material would hold moisture strongly by capillary action. Evershead concludes that only a small part of the total moisture forms high resistance paths and that most of the moisture lies dormant in cells and fibers of the insulation. According to Evershead, an increase of electrical stress floods the conducting paths with moisture taken from the reservoirs of dormant moisture and so decreases the resistance as voltage increases. Evershead accounts for this flooding of the moisture paths by the action of electrical endosmose which gives a movement towards the cathode only. Electrical endosmose is essentially a phenomenon of a dielectric liquid and not of a conducting liquid, and it hardly seems possible that moisture in commercial insulation would be pure enough to be considered as a dielectric. Conducting moisture on the other hand would elongate into filaments, the force acting in both directions, both towards anode and cathode. Possibly both actions may take place.

In the above analysis we have considered only the actions that would take place, due to moisture, in a uniform dielectric field. If the field were not uniform,

2. The Characteristics of Insulation Resistance. *Journal of the Institution of Electrical Engineers*, Dec. 15, 1913.

as for instance in the insulation of an electric cable, it seems obvious that the moisture would have a tendency to migrate towards the more intensely stressed portions of the field. One result of this would be an easing off of the gradient where it was steepest. It may possibly be that an actual benefit is derived from the

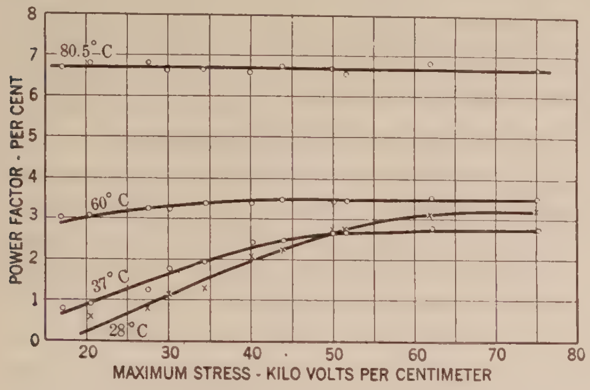

Fig. 10—Power Factor of the Charging Current
Single-phase, 60 cycles.
Single-conductor No. 0000, 20/32-in. paper cable.

moisture in a cable if the potential gradient at the conductor is excessive.

Almost all of the characteristics that it was found should be expected in the hypothetical insulation that has been considered above have been described before as characteristics of ordinary insulation. Perhaps the

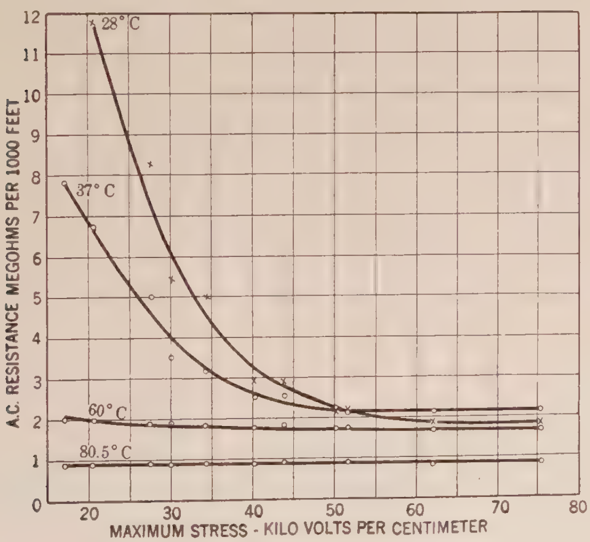

Fig. 11—A-C. Insulation Resistance
Single-phase, 60 cycles.
Single-conductor No. 0000, 20/32-in. paper cable.

characteristics described above as due to evaporation may be considered novel. Among many tests made on cables and other insulation, the author has occasionally found variations that it seemed probable were caused by evaporation. Such a test is given in the appendix.

Appendix

The curves shown in Figs. 10, 11 and 12 were plotted from dielectric loss measurements made upon a single conductor cable insulated with paper and impregnated with mineral oil. This was a special experimental length of 200 feet and it was given less drying than would have been given to a commercial cable of similar design. The curves plotted from the results of the test show the typical characteristics which we have learned to associate with insufficient drying. In a cable where the drying is more complete we find that dielectric loss is proportional to the square of the voltage and that, at any given temperature, power factor and insulation resistance do not change greatly as voltage changes. In this case, however it is only at high temperature that insulation resistance and power factor do not change with voltage. At low temperatures, insulation resistance decreases with

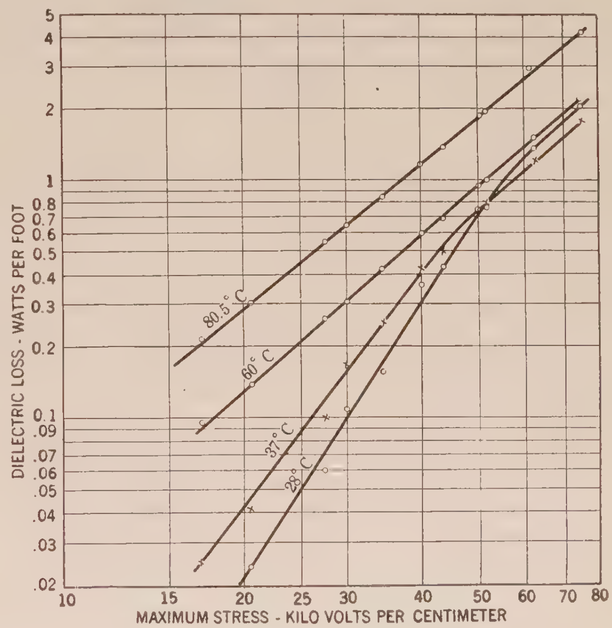

Fig. 12—Dielectric Loss
Single-phase, 60 cycles.
Single-conductor No. 0000, 20/32-in. paper cable.

increasing voltage and power factor increases with increasing voltage. The lower the temperature the greater the rate of change. But in each case if the voltage is sufficiently high a condition of constant insulation resistance and constant power factor is reached. The voltage to bring about this condition depends upon the temperature and is greater for low temperatures than for high.

The explanation for these curves according to the theory given in the above paper is as follows:

Many of the moisture paths or filaments of moisture are, in this case, so large that their sur aces, which dissipate heat, are small with respect to the heat generated in them by electric currents. The moisture therefore becomes hotter than the surrounding dielec-

tric, the actual temperature depending upon both the dielectric temperature and the voltage. Therefore as voltage increases the temperature and conductivity of the moisture increases and the filaments of moisture lengthen. Due to both these causes, a-c. resistance decreases and power factor increases with increasing voltage. But if the temperature of these large filaments becomes sufficiently high, they will be disrupted by evaporation. The cooler the dielectric the greater must be the rise in temperature to reach an evaporating temperature. Therefore the cooler the dielectric the higher must be the voltage to produce evaporation. Evaporation breaks up the large filaments, thus changing the slope of the curves to the horizontal lines that are characteristic of comparatively dry dielectric, in which only small filaments are present.

In the case of the 80.5 deg. curves it would seem that the dissipating action of evaporation must have been complete well below the lowest voltage recorded in the test and that, therefore, the only indication of an excess of moisture is that the power factor is a little higher than might have been expected for a well dried cable.

In the case of the 60 deg. curve the dissipation of moisture, due to evaporation, is almost complete at the lowest test voltage but the last trace of the phenomenon is discernible.

The crossing of the 28 deg. and 37 deg. curves is interesting and apparently means that at 28 deg. a larger part of the total moisture was concentrated in the large filaments than at 37 deg. cent. so that, at the evaporating voltage, the moisture as a whole was hotter in the 28 deg. dielectric than in the case when the dielectric was 37 deg. The fact that at 28 deg. the oil is hard while at 37 deg. the oil is very soft may have bearing on the case.

At high voltages there is much less difference between the curves for different temperatures than there would be for a comparatively dry dielectric, but it must be remembered that the temperature of the conducting moisture paths is not the temperature of the dielectric, nor are the moisture paths in any case all at the same temperature. Above the voltage of dissipation by evaporation many moisture paths would be at evaporation temperature no matter what the dielectric temperature might be. Other paths in the dielectric would be at temperatures between the evaporation temperature and the dielectric temperature. Thus the 80.5 deg. cent. curves differ from the others at high voltage not because the hottest moisture is any hotter than in the other cases but because more moisture is hot.

Design of 45,000-Kv-a Generators, Queenston Plant

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The water power development at Queenston, Ontario, which made use of the combined head of Niagara Falls and the Niagara River Rapids below the Falls, involved the design and construction of, what up to the present time are the largest hydroelectric generators built. Owing to the size limits met in these generators certain interesting design problems were encountered. The more important of these problems dealt with the design of (1) the armature winding, (2) the upper bearing bracket and (3) the rotating spider. The solution of these problems is briefly discussed and a tabulation of major dimensions and weights of the generators is given.

THE initial installation at the Queenston Development of the Hydro-Electric Power Commission of Ontario consists of two vertical shaft type alternating-current generators, each rated at 45,000 kv-a., 12,000 volts, 80 per cent power factor, three-phase, 25 cycles, 187½ rev. per min. nominal, or 49,500 kv-a., 13,200 volts maximum. A third duplicate unit will shortly follow the first two machines.

These units, as far as the records show, are the largest hydroelectric generators yet built and put into service. On account of their size, both in kilovolt-ampere rating and in physical proportions some interesting design problems were raised. These problems were divided into two classes, (1) electrical, and (2) mechanical, with perhaps the latter predominating.

Presented at the Annual Convention of the A. I. E. E., Niagara Falls, Ontario, June 26-30, 1922.

Fig. 1 gives a sectional view of the generator unit. Fig. 2 gives a sectional view of the generator turbine and surrounding structure and indicates the flow of the cooling air through the generator and ducts. Each unit consists of the following component parts:

Stationary armature with base ring.

Upper bearing bracket, which supports the upper guide bearing and the thrust bearing.

Kingsbury thrust bearing.

Revolving field.

Shaft, with one-half coupling forged on the lower end for connection to the turbine shaft.

Lower bearing bracket, which carries the lower guide bearing, brakes and lifting jacks.

Direct-connected exciter.

Design of Armature Winding

The design of the armature winding involved, in addition to the ordinary questions of heating, efficiency, etc., the solutions of four important special problems, namely, (a) to obtain a distribution of the armature coils such as to produce a resultant voltage wave practically free from interference with adjacent telephone lines, (b) to obtain sufficient cross-section of copper in the armature coils to carry successfully the rated current, and at the same time not have the conductors

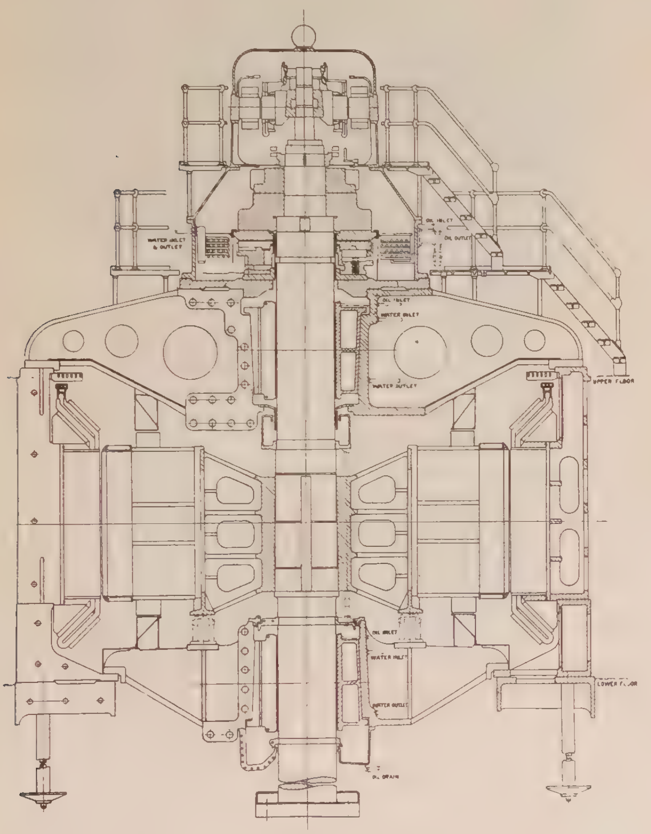

Fig. 1—Cross Section of Generator

of such proportions as to result in excessive eddy current loss; (c) to insulate the coils with materials that could meet the requirements for high dielectric tests and a high maximum temperature limit, even though the operating temperatures are low; and (d) so to support the end windings as to enable them to resist the enormous stresses that would be set up under short-circuit conditions.

The solutions worked out for these design problems were as follows:

(a) It is a well understood condition in the design of electrical generators that starting with the usual field flux form, the actual resultant wave will more nearly follow the desired law, other factors being the same, provided that the conductors, producing the resultant wave, are distributed at a maximum number of different positions about the armature periphery; *i. e.*, in a maximum number of slots. It was not found possible in these units to use an actual number of slots sufficiently large to insure the desired results. However the same effect was obtained by employing

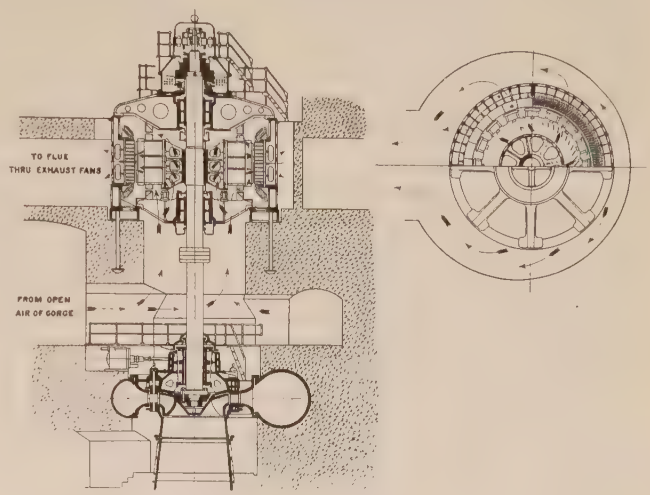

Fig. 2—Showing Flow of Cooling Air

instead of the usual whole number of slots per pole a fractional number of slots per pole. The design selected had 19½ slots per pole which gave a distribution of the winding equivalent to 39 slots per pole. Fig. 3 indicates the distribution of the slots in two successive poles. One pole is shown directly above the other to indicate the relative phase position of the slots. Since the slots per phase in successive poles, in series, are displaced one-half slot pitch with reference to each other, it is apparent that the effect is equivalent to double the actual number of slots per pole.

(b) To minimize the eddy current loss it is necessary

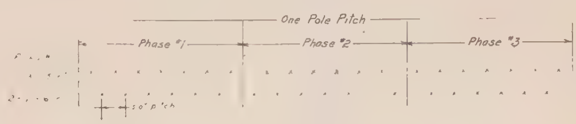

Fig. 3—Armature Winding Distribution
× Represents a slot

(1) to keep the over-all dimensions of the conductors (groups of wires in parallel) small, and (2) to reduce the dimensions, at right angles to the direction of the fluxes, of the individual wires that form the conductors, to relatively small values. To accomplish these results the total copper cross-section per phase was divided into four parallel circuits and the conductor in each of these circuits was subdivided as shown in the slot cross-section, Fig. 4. Each slot contains two coil sides consisting of two conductors each, *i. e.*, four conductors per slot, made up of nine wires in parallel per conductor. Each conductor is divided, depthwise of

the slot, into seven layers, in consideration of the effect of the flux of self-induction. The two layers nearest the air gap were again subdivided into two parts in the width of the slot. The coil was also sunk in the core an additional distance over that ordinarily required for the slot wedge. The latter two features were to minimize the effect of the air gap flux that fringes into the slot.

Each of the wires marked *"A"* in Fig. 4 was insulated throughout its entire length with mica tape to insure positive and permanent separation between the various strands.

Since all the wires are continuous throughout the length of the coil the subdivision, of course, repeats itself in each conductor.

(c) Each group of wires forming a single conductor was insulated with mica tape. The conductors were assembled with mica strips between them to form the coil. The straight section of the coil which is embedded in the armature slot was brushed with bakelite, and then pressed in a hot press to solidify and consolidate the wires. The result of this treatment is a rigid coil in which the wires cannot be disturbed by subsequent insulating and assembling operations.

The straight coil sides were insulated with a micarta-folium wrapper which consists of mica pasted to a very thin paper to give it the necessary mechanical support during the insulation process. The wrapper was first loosely applied to the coil by hand and then ironed

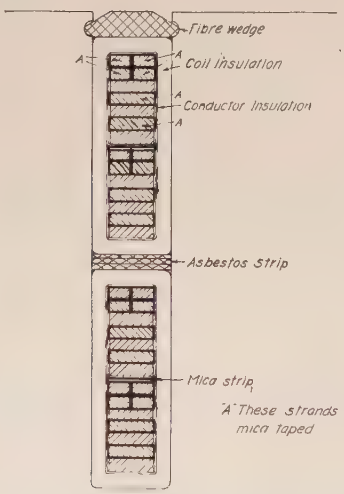

Fig. 4—Section of Armature Slot

into the finished product by electrically heated irons that revolve around the coil softening the bond and exerting a uniform pressure, thus slipping and tightening the wrapper until the insulation takes on the character of a compact wall of mica. The ends of the coil projecting from the core were insulated with mica tape adjacent to the copper and with varnished cloth outside of the mica tape. Varnished cloth tape on the outside of the coil is preferable since it can be sealed to exclude dirt and oil much better than can mica tape. Insulation in the form of narrow tape was used on these parts in order that the ends be flexible.

This insulation was required to meet successfully a dielectric test to ground, and between phases, of thirty thousand volts for one minute. It was also required that it safely withstand a maximum total temperature of 150 deg. cent.

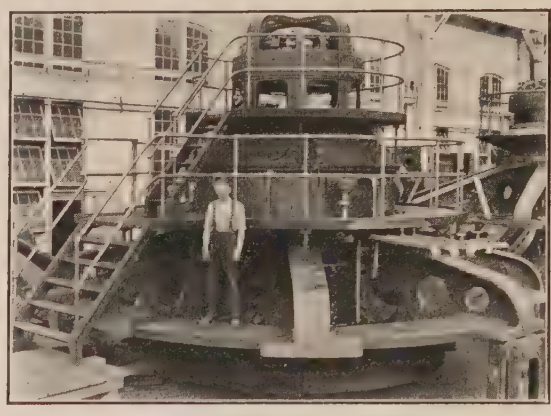

Fig. 5—Upper Bracket with Thrust Bearing, Exciter, Platform and Stairway Assembled

(d) The coil ends were bent away from the air gap at an angle of about 45 degrees to provide space below the boreline for the clamping blocks. The coil ends were braced against distortion under short-circuit conditions by clamping them with through bolts between parallel insulating blocks which are bolted to angle-shaped brackets attached to the frame. This construction is shown in the cross-section views of the generator, Figs. 1 and 2. It was required that this bracing be capable of supporting the coil ends, with the generator short-circuited at its terminals under full voltage.

Design of Upper Bearing Bracket

It was required that this member support the combined loads due to the generator rotor, exciter, turbine runner, shaft and unbalanced water thrust amounting to approximately 1,000,000 pounds. Its design involved the consideration of three principal requirements, namely, (a) the fundamental requirement that it be capable of supporting the load within the safe limits of the material used; (b) that when fully loaded the deflection from the horizontal be less than the clearances between the turbine and generator rotating and stationary parts, and (c) that the character of the material and the design used be such that any vibrations set up by unbalanced conditions in the turbine would not be taken up by the bracket and transmitted to the generator stator.

Obviously these matters are so interwoven that they cannot be considered independently and, therefore, will not be taken up separately.

In designing this supporting member consideration was given to the use of three materials, structural steel, cast steel and cast iron. All factors considered, cast iron seemed the one best suited to the purpose. It was found in considering steel, either structural or cast, that while the requirements of ultimate strength could be readily met, its high degree of flexibility and resilience made it necessary to use sections greatly in excess of the requirement for strength in order to limit the deflection and the possibility of sympathetic vibrations. As the sections required with steel to meet the latter requirements approximated those needed in cast iron for strength, and as cast iron is not as flexible or resilient as steel, the iron was selected.

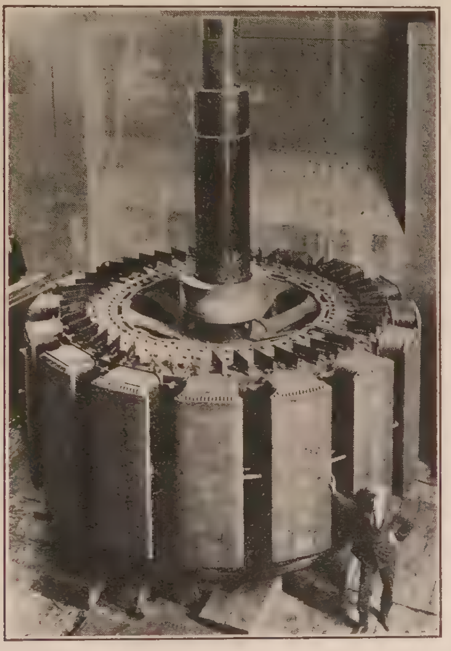

FIG. 6—ROTATING PART

As the top surface of the upper bracket forms the bottom of the thrust bearing reservoir it is necessary that this casting be impervious to oil leakage. It is very difficult, if not impossible, to obtain steel castings that will entirely meet this requirement whereas there is no difficulty in obtaining cast iron that is perfectly homogeneous and oil tight. As the matter of oil leakage is one of no small importance in the operation of such a unit this was also a deciding factor in determining the selection of the bracket material.

This bracket, Fig. 5, in the finished design used sections approximately 2 inches thick and a maximum height at point of load application of 5½ feet.

DESIGN OF ROTATING SPIDER

Owing to the physical dimensions of the rotating spider the particular problem in the design was to select a construction in which the material throughout would be of uniform quality. On account of the well-known difficulties in making castings of such large sections and of obtaining uniformly homogeneous metal, it was impossible to make the spider of the ordinary "cast wheel" type. The "laminated rim" type of design, Fig. 6, was therefore adopted as the one best suited to meet the requirements.

This design used an inner cast steel spider which consists of a hub and arms but has no rim. The rim is built up using over-lapping $\frac{1}{16}$-in. rolled steel plates that are dovetailed to the spider arms in a manner similar to that used in attaching the armature punchings to the frame. In addition to being attached to the spider by the dovetails, the rim is clamped between heavy steel end plates by means of through bolts that pass through the entire laminated rim and the end plates. This design results in a rim structure of perfectly uniform material of known quality, to a degree impossible to obtain with castings. In this design the rim was not only self supporting as to radial stresses, entirely neglecting the dovetails, but was also capable of carrying the weight of the poles and field coils when operating at a maximum speed of 347 rev. per min.

The two large vent spaces provided in the central part of the spider were to provide additional cooling air inlets for this part of the unit.

OPERATING RESULTS

With the generators in regular commercial service and operating under rated load, the maximum temperature rise measured by embedded temperature detector is 55 deg. cent.

GENERAL DIMENSIONS AND WEIGHTS

The principal dimensions and weights of the generators are as follows:

Maximum over-all diameter	25 feet.
Height from floor line to top of frame	13 ft. 8 inches.
Maximum over-all height from floor line..........................	26 ft. 10 inches
Diameter of shaft at coupling.......	2 ft. 6 inches
Total weight of copper............	50,000 lb.
Weight of rotating part............	615,000 lb.
Total weight of generator unit......	1,400,000 lb.
Load on thrust bearing............	1,000,000 lb.
Flywheel effect of rotor............	21,500,000 lb-ft.^{2}

EXPERIMENTAL 600,000-VOLT LINE

An experimental transmission line for operation at 600,000 volts recently completed at Purdue University. At the present time very little is known about the phenomena of high-tension transmission in excess of 220,000 volts, so the engineering experimental station of Purdue has begun work to obtain definite data. The line is 1700 feet in length and consists of three 600-foot spans of steel core aluminum cable, supported on four steel towers 65 feet high. The cross arms are 40 feet long, and the 15-unit suspension insulators are hung in such a manner so that they may be readily moved in different directions from 16 to 40 feet without taking down the cables.

The first study to be undertaken is corona losses.

Corona in Air Spaces in a Dielectric

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Review of the Subject.—*The consideration of the extreme care necessary in preparing samples of a dielectric for test for electrical properties led to the investigation of the effect of air spaces, purposely formed of definite thickness and location, upon the power factor. This work in a way is an extension of some work done by Clark and Shanklin and Shanklin and Matson several years ago on air spaces in high voltage cables and wrapped armature coils. In their investigation the effect of assumed air spaces of indefinite thickness, extent, pressure and location was shown by plotting effective resistance from the formula* $R = \frac{E^2}{W}$ *against potential gradient. A characteristic curve was obtained, a sharp inflection point in the curve being interpreted as indicating the starting point of corona.*

In the work by the writer, various materials were investigated both with air spaces excluded as much as possible, and with air spaces of definite thickness, extent, and location at atmospheric pressure. The results were plotted showing variation of power factor with potential gradient. A definite increase in power factor with potential gradient indicated the starting of corona. The thicker air space with a given thickness of dielectric showed the more abrupt change in power factor, and this took place at a lower potential gradient. By plotting power factor against voltage, a maximum was shown indicating that a saturation of ionization was approached which resulted in a decrease in power factor.

By plotting effective resistance assuming the resistance to be in series with the dielectric and to be given by the formula $R = \frac{W}{I^2}$ *a very definite change in R as well as in power factor indicated the beginning of corona. The curve obtained in this way did not possess superior advantages over the plot for power factor for indicating corona and had the disadvantage that the points were somewhat scattered on the upper range of potential gradient.*

The results of the investigation show that:

1. It is extremely difficult to exclude air spaces from a dielectric so that it does not result in corona formation. Corona is shown by a more or less abrupt change in power factor with potential gradient.

2. The abruptness of the change in power factor with potential gradient depends upon the thickness of the air space, the thicker the air space the more abrupt the change.

3. The thicker the air space for any given thickness of dielectric the lower the potential gradient to produce corona.

4. The potential gradient to produce corona not only depends upon the thickness of the air space but also upon the extent of the air space as shown by observations on different areas of air space of the same thickness.

5. A maximum of power factor is reached with potential gradient indicating that saturation of ionization is approached after which the value of power factor decreases with potential gradient.

WHEN measuring dielectric losses and power factor of insulating materials, it is of great importance that air should be excluded from the surfaces of contact with the electrodes and from the interior of the material. At low stresses, the losses and power factor are found to be lower than they should be because of the highly insulating air space. Likewise, the effective area of the material is smaller and consequently the measurements of the electrical properties are incorrect. At higher stresses, the gas spaces become ionized and corona formation results with the attendant increase in losses and power factor.

The phenomenon of corona formation in connection with loss measurements in high voltage cables and armature coils was observed by Clark and Shanklin[1] and was further studied by Shanklin and Matson[2]. In high-voltage cables and armature coils, air spaces no doubt exist which result in corona formation when overstressed.

In the case of materials built up in the form of cables and coils, it is practically useless to speculate from loss measurements as to the thickness or extent of the air space, its pressure and location. No assumption can safely be made even as to the partial pressures due to entrapped air and the vapors from the materials themselves.

It has been recognized that when an insulating space is filled with a composite dielectric such as a solid material and air having quite different dielectric constants the result is that the dielectric strength of the combination is lower than either one separately. For instance, when air which is a good dielectric and mica which is an excellent dielectric are used in combination, the result is a poorer dielectric than either used separately. This is due to the fact that an increased number of lines of force are concentrated in the air space which has the lower permittivity and this results in breakdown which throws a greatly increased stress upon the mica.

Air in a dielectric in the form of a cable, a wrapped armature coil or test piece with specially applied electrodes, may exist in two ways. Either, it may be in the form of an air film or bubble between layers or between the dielectric and the conductor, or it may be in the form of occluded gases in the interstices of the material. Both no doubt, produce losses at high-voltage stresses, though it is generally believed that air in films or bubbles gives rise to the greater part of the losses. It is impossible to separate the effect of occluded gases since the gases cannot be eliminated except by heat and vacuum, nor can they be excluded except by filling the spaces by some impregnating

1. Clark and Shanklin, A. I. E. E. TRANS. Vol. XXXVI, 1917, p. 447.
2. Clark and Matson, A. I. E. E. TRANS. Vol. XXXVIII, 1919, p. 489.

Presented at the Annual Convention of the A. I. E. E. Niagara Falls, Ont., June 26-30, 1922.

compound. By this process, however, the dielectric properties of the original sample are changed.

Though it is a difficult problem to study the effect of occluded gases on the losses of a dielectric material, the effect of various air spaces, which is by far the greater source of losses, may be studied by actually testing materials in which definite spaces are made

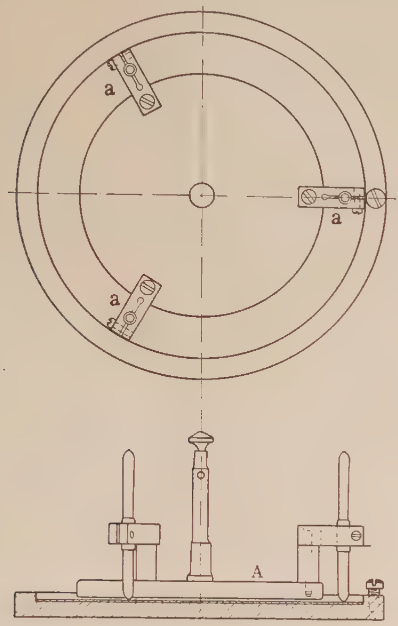

Fig. 1—Testing Electrode

and in which their locations are definitely established. It must be understood that the effect of occluded gases is also included in this effect, though in comparison with the former, it may be considered practically negligible.

The samples of insulation tested in connection with the effect of air spaces in this investigation, were all in the sheet form. In all cases except for glass, the surface of the material was made plane by fastening to an accurately plane brass disk. In the case of glass, the plane plate was floated upon mercury, the precaution being taken to free as nearly as possible any entrapped air from the under surface. The top electrode applied to the sample was so made that it could be adjusted for any desired air space between it and the specimen. This is shown in Fig. 1. The electrode *A* was a brass disk 7. 5 cm. in diameter with carefully rounded edges and polished surface. This was fitted with three arms *a, a, a,* through the outer ends of which passed three insulating quartz rods which formed a tripod support for the electrode. The quartz rods extended well out from the edge of the disk so that the insulating support was far removed from the electric field, since it is very essential that no dielectric having a different permittivity should be introduced in the air space in an electric field.

The air spaces of uniform thickness were formed between the upper disk and the dielectric by adjusting the quartz rods with spacers. The rods were then clamped in place by tightening the screws in the arms provided for that purpose, as shown in the diagram.

The loss measurements from which the power factor was determined were made with a sensitive electrostatic wattmeter. The current was measured by a sensitive electrometer shunted across a part of the non-inductive resistance of the wattmeter. The testing transformer was of 5 kw. capacity and the voltage was known to have a good sine wave. The voltage was varied by potential taps from the secondary of the transformer except where readings were desired at voltages between these steps. In this case, the voltage from the next step to the transformer, was varied by applying voltages to the primary by a potentiometer arrangement. The current in the potentiometer was quite large so that wave distortion was not introduced. Alternating voltages of 60 cycles were used throughout this investigation.

When materials with air spaces were tested, the potential gradient was increased to a point where there was a quite abrupt change in the losses and the current. The abruptness of this change was dependent upon the thickness and extent of the air space. Graphically the formation of corona is very clearly indicated by plotting power factor which involves both watts loss and current against potential gradient. The potential gradient was taken as volts per centimeter between the plates. For all materials having appreciable

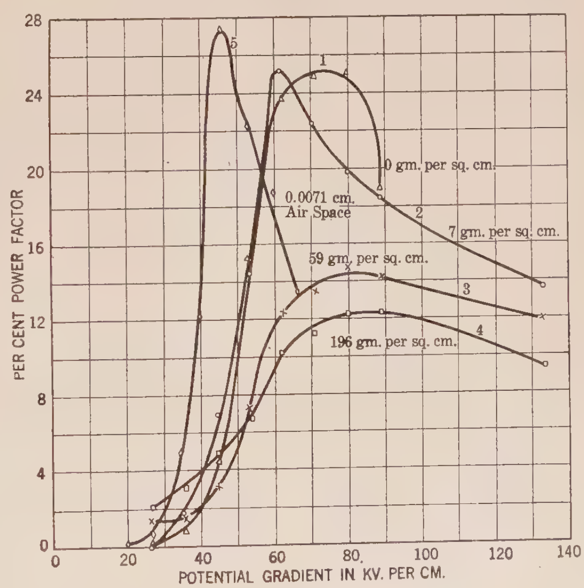

Fig. 2—Corona in Air Spaces

60 Cycles

White India mica, 0.026 cm. thick.

Variation of power factor with pressure on specimen.

air spaces the power factor is low before corona forms, after which it rises rapidly to a maximum and then again decreases with potential gradient, the sharpness of the fall depending upon the thickness of the air space.

A number of materials were tested with variations

of air spaces and the results are shown by the following curves.

A sheet of White India mica about 11 cm. in diameter and 0.023 cm. thick, was selected for test. The specimen was clear and fairly free from air spaces between laminations. It was first tested by placing

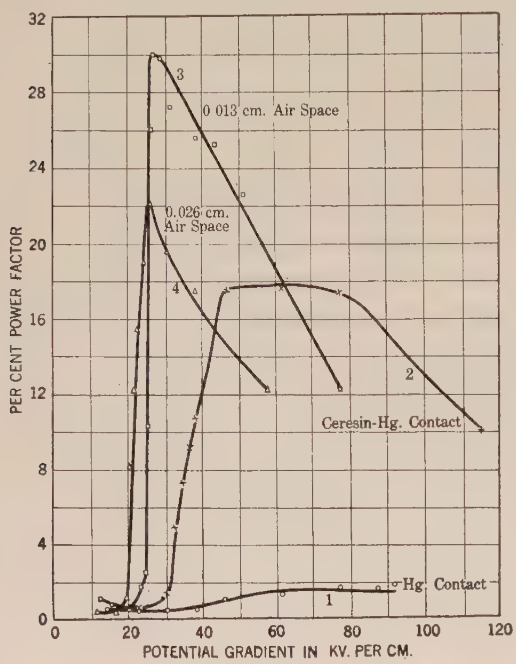

Fig. 3—Corona in Air Spaces
60 Cycles
White India mica, 0.026 cm. thick.

the mica upon the brass plate and then laying the other electrode on the top surface. The tests were then repeated placing different weights upon the upper electrode. The variation of power factor with potential gradient for various pressures from zero where the weight of the electrode was just supported by the quartz rods to 196 grams per square centimeter are shown in Fig. 1. In these curves, the thickness of the air spaces were not known, though it can be presumed that they decreased with pressure. Curve 5 was obtained by raising the upper electrode a distance of 0.007 cm. above the mica. In each of these cases, there was an air space on each side of the mica presumably of equal thickness except for the last where the greater air space was on the upper side. In general, the power factor at low voltage was always greater for the greater pressure or thinner air space. Likewise, the potential gradient to produce corona was lower for the smaller pressure or thinner air space.

The change in power factor with potential gradient was more gradual the thinner the air space. With a thicker air space, 0.007 cm., the change in power factor was quite abrupt. It is also observed that in all these curves a maximum power factor was reached, after which the power factor decreased in value. In this test, the specimen of mica was not perfectly flat so that the air spaces were not of uniform thickness. A test for power factor was now made with mercury electrodes care being taken to eliminate as far as possible any air films. The result is shown by Curve 1, Fig. 3. It is to be observed that the increase in power factor did not take place until a value of 40 to 45 kilovolts per centimeter was reached. At that point, the increase was not great but the curve clearly gives evidence of an air film either at the surfaces of contact or between laminations. The sample was now fastened to the lower plate by melting a layer of ceresin upon it and pressing the mica upon it by a one half-ton press. Small air spaces were still clearly shown in the surface of contact even though the whole had been heated for some time at about 100 deg. cent. and had been pressed as stated. This fact illustrates how difficult it is to free a test piece from air spaces. The result of the test with mercury contact on the top surface is shown in curve 2. The abrupt change in power factor now occurred at a lower value, about 30 volts per cm. A flat-topped maximum was quickly reached after which the power factor decreased. For an air space of 0.013 cm. the corona started at 22 kv. per cm. and a sharp maximum of 30 per cent power factor was reached at 27 kv. per cm. With a 0.026-cm. air space, corona started at about 19 kv. per cm. and a sharp maximum

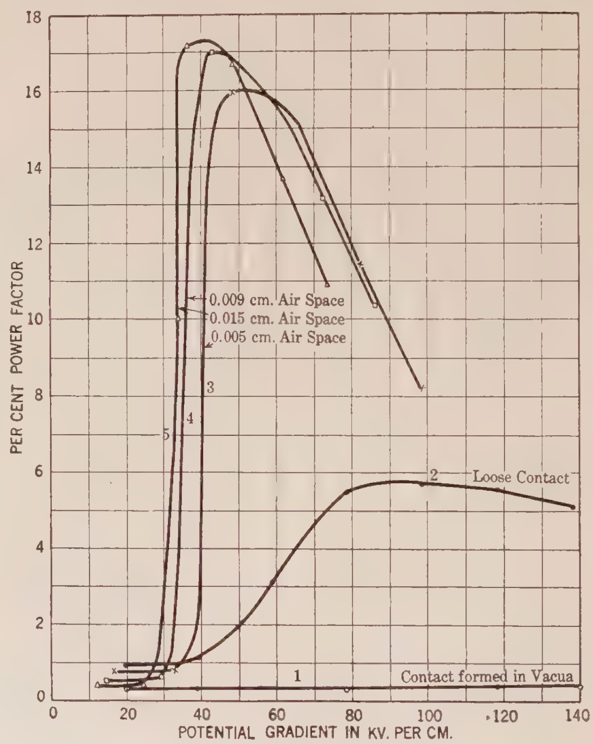

Fig. 4—Corona in Air Spaces
60 Cycles
Ceresin wax layer, 0.025 cm. thick

was reached at 26 kv. per cm. The maximum for this greater air space was not so great as for the 0.013-cm. air space, which is somewhat contrary to what was generally found. This may have been caused by a change in surface conditions due to the previous application of voltage.

In Fig. 4, are shown the results for a ceresin wax layer 0.025 cm. thick. Curve 1 was obtained by melting the ceresin wax in vacuo in a shallow plane-bottom tray and lowering upon it in vacuo the upper electrode adjusted for the desired thickness. The vacuum was then released and the specimen was allowed to cool. In this way, it was thought that the sample was completely rid of moisture and that air spaces were not included. The results of tests are shown in Curve 1. The curve shows only a very slight uniform rise of power factor up to 140 kv. per cm. Another layer melted in vacuo was prepared in the shallow tray and was placed upon a level surface and allowed to solidify. In this way a smooth layer of uniform thickness was obtained. Curve 2 was obtained by laying the upper electrode loosely upon the layer of wax. Curves 3, 4 and 5

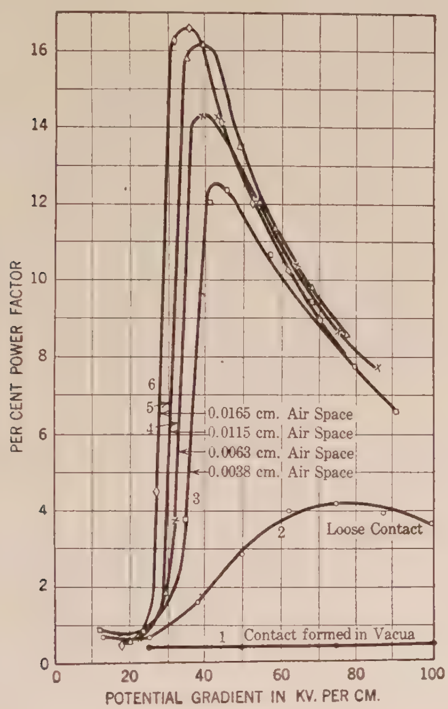

Fig. 5—Corona in Air Spaces
60 Cycles
Ceresin wax layer, 0.041 cm. thick.

were obtained with air spaces 0.005, 0.009 and 0.015 cm. thick, respectively. As shown by these curves corona formed at lower potential gradients for the thicker air spaces. Likewise, for the thicker air space, the maximum value of power factor was greater, as one would expect if the greater loss took place in the air space.

In Fig. 5 are shown the results of tests for a thicker layer of wax (0.041 cm.) prepared in the same manner as above. The results are much the same as in the previous test except that for the thicker layer corona took place at a lower potential gradient and the values of the maxima were slightly lower. Fig. 6 shows results for a still thicker layer of wax (0.056 cm.). For this thicker layer the potential gradients for corona

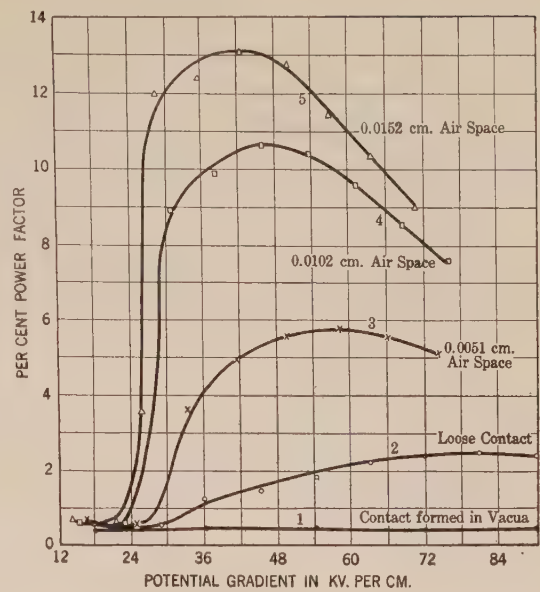

Fig. 6—Corona in Air Spaces
60 Cycles
Ceresin wax layer, 0.056 cm. thick.

formation were at still lower values, but the maxima of power factor were lower. Further, with this thicker layer of wax, there is a greater variation in the maxima of power factor for the different thicknesses of air spaces.

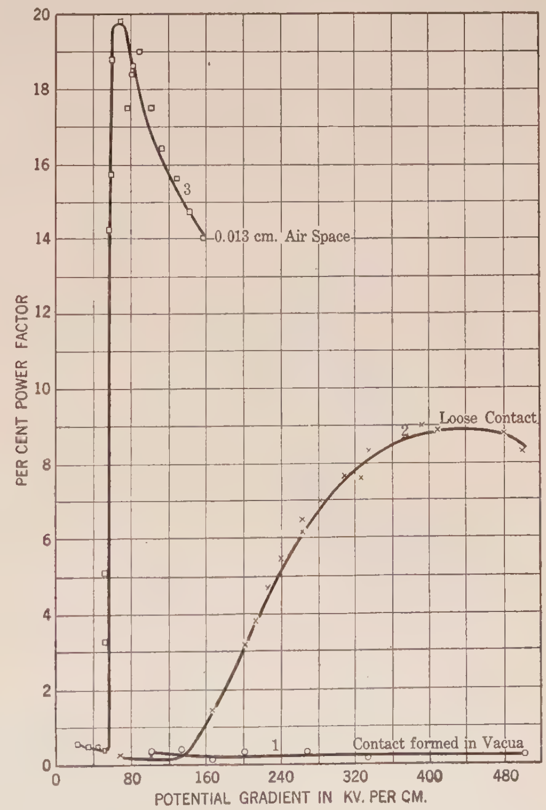

Fig. 7—Corona in Air Spaces
60 Cycles
Three sheets condenser paper impregnated with ceresin in vacuo
Total thickness, 0.006 cm.

In Fig. 7 are shown the results for condenser paper impregnated in ceresin. Curve 1 was obtained by drying and impregnating and placing the upper electrode on the material in vacuo. In this way all moisture and air should have been completely removed. The curve shows that the power factor is independent

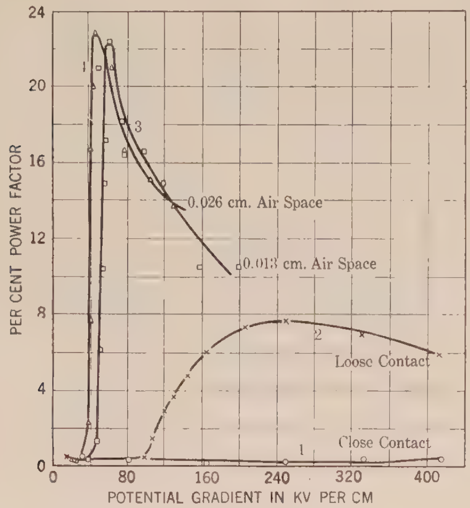

FIG. 8—CORONA IN AIR SPACES

60 Cycles

Six sheets condenser paper impregnated with ceresin in vacuo. Total thickness, 0.12 cm.

of potential gradient. Curve 2 was obtained by placing the upper electrode loosely upon the impregnated condenser paper. Curve 3 was obtained with the

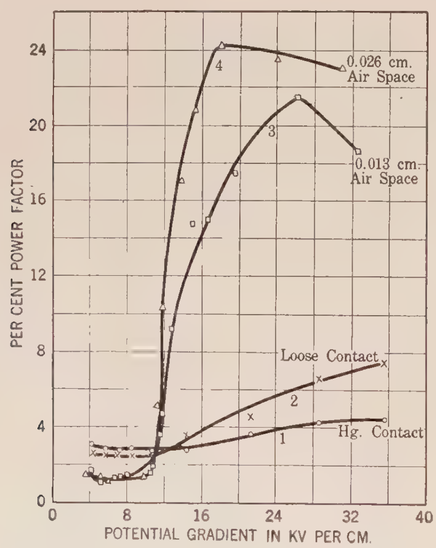

FIG. 9—CORONA IN AIR SPACES

60 Cycles

Glass plate, 0.140 cm. thick.

same specimen with a 0.013-cm. air space between the impregnated paper and the upper electrode.

The curves in Fig. 8 were obtained in the same way as above, with six sheets of condenser paper prepared in the same way. The curves 3 and 4 for air spaces of 0.013 cm. and 0.026 cm. show the same characteristics, the curve for the thicker air space showing corona at a lower potential gradient but both having about the same maximum value of power factor.

Fig. 9 shows the curves obtained with a glass plate

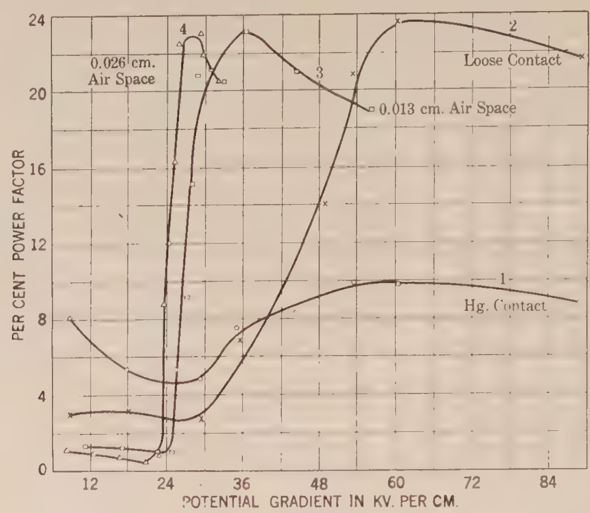

FIG. 10—CORONA IN AIR SPACES

60 Cycles

Treated cloth, 0.023 cm. thick.

0.140 cm. thick. All the curves were obtained with the plate floated upon mercury with especial care taken to exclude as far as possible any air films on the bottom surface. Curve 1 for mercury contact also on the top surface shows slight corona formation at 21 kv. per cm.

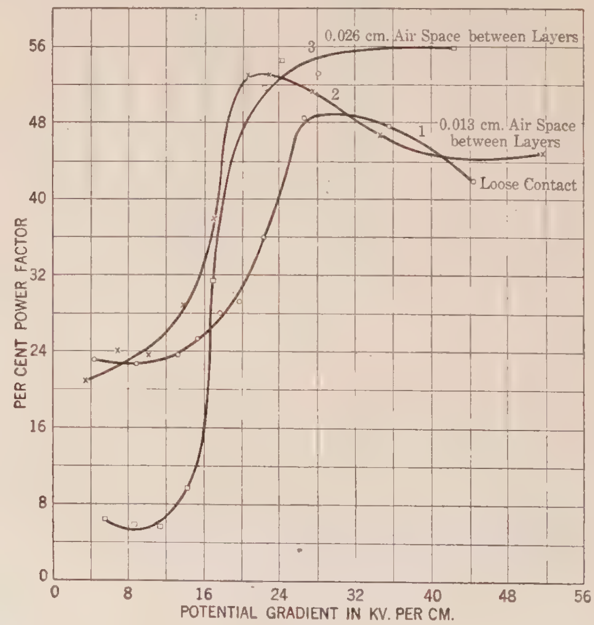

FIG. 11—CORONA IN AIR SPACES

60 Cycles

Treated cloth, 0.023 cm. thick, two layers. Air spaces between layers.

Curve 2 for loose plate contact shows corona at a lower value, about 12 kv. per cm. With air spaces of 0.013 and 0.026 cm., corona was shown at about 11 kv. per cm. The difference between the values of potential

gradient to produce corona was small because of the thinness of the air space in comparison with the thickness of the glass plate.

Fig. 10 shows the results for treated cloth 0.023 cm. thick. The cloth and plate were given a very thin coat of varnish and pressed together and placed in an oven at 100 deg. for two hours. At the end of this time, they were placed under a one half-ton press and allowed to cool. By this treatment, the varnish was not completely dried as shown at the end of the experiment. Curve 1, obtained with mercury contact on the upper surface, shows a minimum of power factor with potential gradient followed by a maximum after the beginning of corona. Curve 2, for loose contact, shows only a slight minimum if any but a much greater maximum. Curves 3 and 4 show a very abrupt change in power factor at about 25 and 23 kv. per cm. respectively. With these curves as with others, the falling off of power factor with potential gradient after the maximum was reached was more rapid with the thicker air space. In these curves where the power factor is larger at low voltages, the effect of air spaces in lowering the power factor before corona forms is more clearly shown.

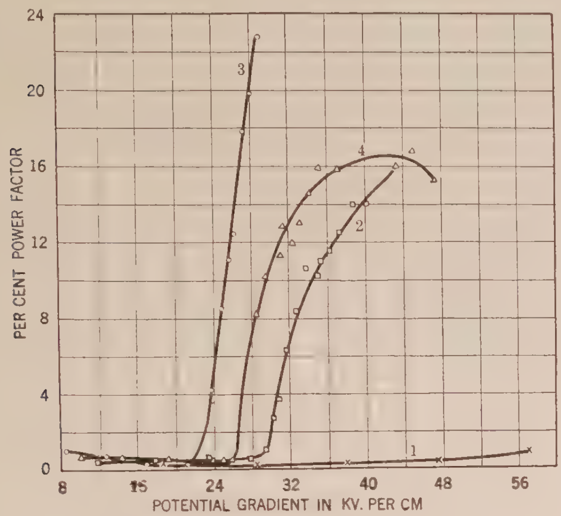

Fig. 12—Corona in Air Spaces

60 Cycles

Manila paper, 15 cm. square, impregnated with petroleum jelly. Thickness, 0.021 cm.
1—One-layer paper, close contact.
2—One-layer paper, 0.013-cm. air space.
3—One-layer paper, 0.026-cm. air space.
4—One-layer paper covered with second layer having 7.7-cm. hole.

Fig. 11 shows the results for two layers of treated cloth each rubbed with a slight amount of vaseline and each pressed tightly to a surface of each plate. The sample was not heat-treated in any way. Curve 1 was obtained by laying one plate upon the other with the surfaces of the two sheets of treated cloth in loose contact. Curves 2 and 3 were obtained with air spaces of 0.013 and 0.026 cm. between sheets respectively. These curves are less in agreement with the general types of curves previously obtained, due, no doubt to change in condition of the specimen during continued application of voltage.

Fig. 12 shows the results for manilla paper 0.021 cm. thick, vacuum dried, and impregnated with petroleum jelly. This material was supplied through the courtesy of the Habirshaw Electric Cable Co. Curve 1 was obtained with one sheet of paper. The excess of petroleum jelly was removed and air bubbles were excluded and pressure was applied to secure close contact. The curve shows that the power factor was practically independent of voltage. At slightly higher potential gradient, breakdown occurred but there was no noticeable corona formation up to that point. Curves 2 and 3 were obtained with air spaces of 0.013 and 0.026 cm. respectively. The potential gradient was not raised to the point where a maximum power factor was obtained, but the curves show a corona formation for the thicker air space at a lower potential gradient.

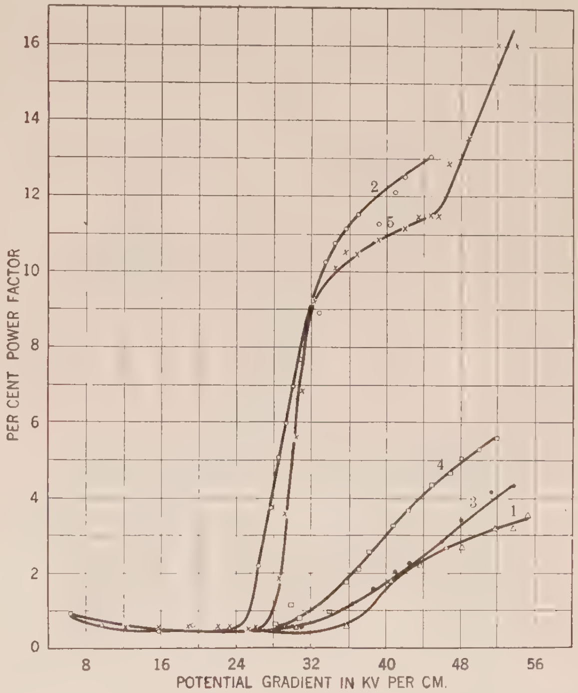

Fig. 13—Corona in Air Spaces

60 Cycles

Manila paper impregnated with petroleum jelly.
Thickness, 0.021 cm.
1—Three layers of paper.
2—Three layers of paper, middle layer perforated with 7.7-cm. hole.
3—Three layers of paper, middle layer perforated with one 0.58-cm. hole.
4—Three layers of paper, middle layer perforated with five 0.58-cm. holes located at the corners and center of a 6-cm. square.
5—Three layers of paper, middle layer perforated with fifty-one 0.58-cm. holes arranged at the corners of 1.4-cm. squares.

Curve 4 was obtained by placing upon the lower sheet of paper a second sheet having a hole 7.7 cm. in diameter. Upon this second sheet was placed symmetrically a brass disc about 10 cm. in diameter. In this way a confined air space 0.021 cm. thick was formed. The characteristics of this curve are not different from what had been obtained with the unconfined air space.

The curves in Fig. 13 were also obtained with the

manilla paper impregnated with petroleum jelly. Curve 1 was for three layers closely pressed together by a one half-ton press. The curve shows that all air spaces were not eliminated. Curve 12 shows the results for a 7.7-cm. hole in the central part of the middle sheet. Curve 3 is for a hole 0.58 cm. in diameter in the middle sheet. The curve shows but slight difference to that for the three whole layers, indicating that the air spaces in the latter were comparable in effect with the air space intentionally formed. Curve 4 was obtained with five holes of the same size grouped near the center of the space beneath the upper electrode. Curve 5 was obtained with fifty-one holes of the same size laid out in regular pattern in the middle sheet between the electrodes. This curve does not

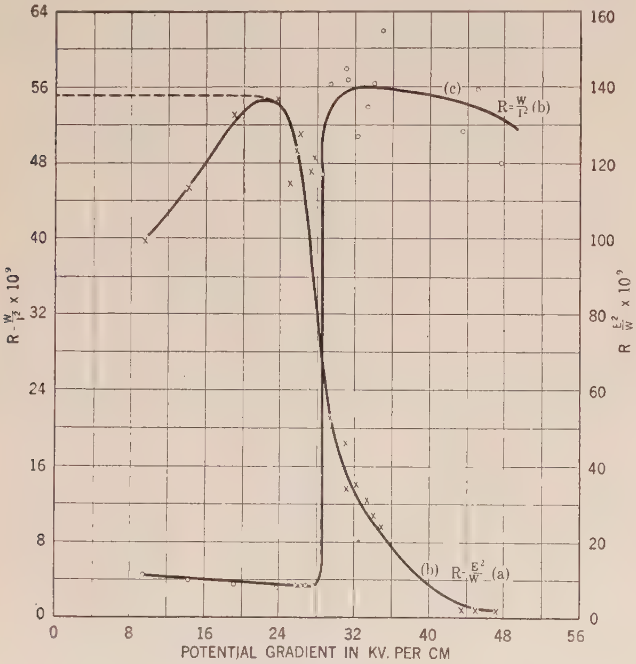

Fig. 14—Corona in Air Spaces

60 Cycles

Manila paper impregnated with petroleum jelly.

Two layers of paper, one perforated with hole 7.7 cm. in diameter.

differ greatly from Curve 2 for one large hole 7.7 cm. in diameter. In all these curves for the same thickness of dielectric, corona formation is indicated at the lower voltage for the greater area assuming the thickness of air space the same. Curve 5 which was carried to a higher potential gradient than Curve 2 shows a marked increase in power factor above 46 kv. per cm. This may have been due to heating as the voltage was in the neighborhood of breakdown.

In the work referred to by Clark and Shanklin[1] they plotted effective resistance considered in parallel with the dielectric against potential gradient where they defined effective resistance by the expression

$R_{eff} = \frac{E^2}{W}$ where E is the potential in volts and W is the watts loss. These investigators state that the characteristic form of curve is hard to obtain because of the exactness with which E is obtained, the square of which appears in the formula. If it is assumed that the effective resistance is in series with the test sample and the value of this quantity is obtained by the expression

$R_{eff} = \frac{W}{I^2}$ where W is the loss and I is the current

much more definite curves may be obtained though they are quite different. As an example, the data from which Curve 4, Fig. 14 was obtained were used to calculate the effective resistance by the two formulas. These are shown in curves a and b, Fig. 14. It is shown that the characteristic curve obtained by Clark and Shanklin, indicated by the dotted curve, is not obtained though no great trouble was taken to obtain very accurate values of E. This curve, however, is as near the form of the characteristic curve obtained by Clark and Shanklin as any which have been plotted by the writer. Curve b calculated by the formula

$R_{eff} = \frac{W}{I^2}$ is quite definite and shows quite sharply

the starting point of corona. Further the points below the starting point of corona are quite definite in comparison to those for the same data plotted in curve a. The points in the upper range of the Curve b, on the other hand, are not as definite as those in Curve a. The points in Curve a by the formula probably are indefinite more on the account of inaccuracy in the measurement of W than of E, since at low-potential gradients the losses are quite small and a large per cent of error may be made in measuring a very small quantity. Because the points are definitely determined for power factor, over the whole range of potential gradient, and since this plotting shows definitely the starting point of corona, the writer in this investigation chose this method of plotting results to show the starting point of corona caused by the ionization of air spaces in a dielectric.

In this paper so far, as well as in the paper by Clark and Shanklin, no attempt has been made to analyze the mechanism of the phenomena observed. No doubt the mathematical relations of the quantities involved could be worked out but that is outside the scope of the present paper. Physically, the relations shown in this paper may be expressed as follows: For any combination of air and a dielectric tested at low voltage, the losses should be in the dielectric, since the number of free ions in the air are small compared to the number in the dielectric. The losses in a good dielectric such as those used in these experiments should be in the nature of hysteresis losses rather than true ohmic losses, and would best be represented as a resistance in series with the dielectric. As the potential gradient is raised the free ions in the air space, though few in number at the start, soon acquire sufficient velocity

to ionize other gas molecules in their path by the process known as ionization by collision. In this way, the ionized gas molecules are greatly multiplied until a point is reached where the characteristic discharge known as corona takes place. At this point the greater proportion of the losses occur in the air space and a large increase in current and losses are observed, the relation being such as to greatly increase the power factor. As the potential gradient is increased more ionization due to the increased velocity results and this produces greater losses and greater power factor. However, a point is reached in potential gradient where the greater proportion of gas is ionized so that further increase in potential gradient does not produce a corresponding increase in ionization. At this point then the change in the rate of increase of losses decreases and a lowering of the power factor is observed. According to this theory then these changes should be more pronounced with the thicker air space since the rate of multiplication of the ions is proportional to the distance they travel in the air space. This is in agreement with the observed results. With a thin air space, the free ions do not acquire a sufficient velocity to produce other ions in their path, hence corona is not observed at as low a potential gradient as for a thicker air space. Hence for a thin air space a higher potential corresponding to a higher velocity of the ions is necessary for corona formation, as has been shown in this investigation.

It is realized that the scope of this work may be extended and application be made to practical problems in which something is known of the actual conditions existing. Only the simplest conditions have here been considered, for it has been realized that the subject of losses in insulating materials is sufficiently complex under these conditions and that the introduction of many variables which may be eliminated only introduces confusion and speculation.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

INFLUENCE OF DIRT ON LIGHT OUTPUT OF LAMPS

It is a fact well known to lighting men that the amount of illumination obtained from lighting equipment decreases gradually but surely with length of service, due to dust and dirt which accumulate on the surfaces of the lamp and the reflector. A few months ago an investigation was undertaken to classify the kinds of dirt which may be expected to accumulate on the lamps in representative industries and to determine just how much the light output of lamps may be increased by removing these dirts.

To determine the kinds of dirt to be found on lamps in regular use in the various industries, several companies were visited and from one to three lamps taken from each. The companies visited were representative of the automobile, paint and varnish, chemical and storage battery industries; machine shops, foundries, and transportation offices and warehouses. It was not attempted to examine a large number of lamps, but the results of the investigation indicate the effect of dirt on lamps in general. Lamps which had accumulated dust and dirt typical of each industry were selected.

The total number of lamps used by these companies is approximately 16,000, about 85 per cent of which are clear lamps. Of the companies visited, 60 per cent do not clean their lamps at all, 33 per cent clean them at infrequent intervals, and about 7 per cent clean lamps frequently at regular intervals. It should be borne in mind that this survery was made at a time of financial stringency, when many of the companies were operating only three or four days a week, with reduced forces. Maintenance men whose duties include regular cleaning of the lighting installations had been temporarily released and a much higher percentage of companies which clean lamps frequently can be expected when these men return to work under normal manufacturing conditions. Typical cleaning materials found in use at the companies visited were soap and water, Gold Dust, and Oakite.

Tables I and II show the kinds of dirt found in 24 different service locations and the foot-candle measure-

TABLE 1

Illumination Incr ases Obtained by Removing Various Kinds of Dirt from Lamps Selected from Actual Service Conditions

Lamp No.	Watts	Kind of dirt on lamp	Before cleaning (foot-candles)	After wiping (foot-candles)	Per cent increase in illumination	After washing (foot-candles)	Per cent increase in illumination
1	200	Dry machine shop dirt	14.0	23.0	64	23.0	64
2	200	Dry machine shop dirt	5.5	16.0	191	16.0	191
3	75	Smoke and dust	8.0	11.0	38	11.0	38
4	40	Smoke and dust	4.5	8.5	89	8.5	89
5	40	Acid fumes	7.0	11.0	57	11.0	57
6	200	Fly specks and office dirt	11.5	14.0	22	16.0	39
7	100	Rosin vapor	2.75	3.75	36	3.75	36
8	50	Linseed oil	1.75	2.75	57	2.75	57
9	150	Coke, lamp black, graphite dust	8.0	17.0	112	17.0	112
10	40	Dust and vapor from lamp black manufacture	2.75	4.5	64	4.5	64
11	40	Dust and vapor from lamp black manufacture	2.0	3.75	87	3.75	87
12	100	Coke dust	2.75	6.5	136	6.5	136
13	25	Oily dirt from lathes	1.5	2.75	83	5.0	234
14	25	Oily dirt from lathes	2.2	4.5	104	5.5	150
15	100	Asphaltum vapors	8.5	11.0	29	11.0	29
16	100	Gum vapors	5.5	8.0	45	10.0	82
17	40	Paint	3.6	5.5	39	8.0*	122
18	60	Dry gypsum dust	8.0	10.0	25	10.0	25
19	60	Dry gypsum dust	11.0	14.0	27	14.0	27
		Averages			68.6		86.3

*Organic solvent used in cleaning this lamp.

ments, taken from a fixed position, before and after cleaning the lamps. All but two lamps were clear lamps; these two were bowl-frosted lamps.

It will be seen from the two tables that four separate classes of dirt were encountered, these being dust and dry dirt, smoke, etc.; oily dirt and grease; paints, tars, varnish and pitches; and acid fumes, in the order in which they most frequently occur. Oily dirt is encountered more frequently than paints, tars, or pitches, even though more lamps were selected in the latter class. By wiping the lamps taken from this test, it was possible to increase their average light output 68.6 per cent, and when these lamps were washed they showed a total increase in illumination of 86.3 per cent. The increase in the case of those soiled with oil dirt was 147 per cent. Emphasis should be given to the fact that these figures represent the increase of light due to cleaning the lamps only. A much greater increase in useful light will result when the whole lighting unit is cleaned. Hence, the figures in Table II indicate that the regular cleaning, at stated intervals, of lamps and reflectors is desirable in order to avoid a waste of electrical energy and light.

TABLE 2
Summary of Illumination Increases

Classification of Dirt on Lamps	Average per cent increase in illumination after wiping	Average per cent increase in illumination after washing
I Dust and dry dirt	77.7	78.4
II Oily dirt	84.7	147.0
III Paints, tars and pitches	37.2	67.2
IV Acid fumes*	....	....
V All lamps	68.6	86.3

*Bulbs were badly attacked by HF and bases badly corroded by HCl and HNO_3; therefore candle-power measurements were not included.

The preceding paragraphs emphasize the fact that lamps and lighting equipment when not cleaned regularly, become extremely dirty, and the figures for lamps under service conditions demonstrate the surprising increase in illumination caused by cleaning. Since it is necessary to clean lamps frequently at regular intervals, it may be questioned how the different classes of dirt are removed by progressive maintenance men. The answer is simple, because by far the greatest number of lamps may be cleaned by the application of soap and water. Dust and dry dirt are removed by this most common method and also oily dirt and grease. It will be found easier, however, to remove fly specks, smoke, oil and grease by the application of some cleansing agent such as Bon Ami, Old Dutch Cleanser, or Babbitt's Cleanser. The procedure for a thorough job of cleaning usually involves the removal of group of both lamps and reflectors to a central location for washing. If desired, lamps and reflectors may be cleaned without removal from the sockets but the results are usually not as satisfactory. After washing, it is important to dry the lamps and reflectors either with a cloth or in air, free from dust.

Paints, tars, and pitches are encountered comparatively infrequently, but are sometimes very difficult to remove by the usual methods. In these cases an organic solvent such as acetone, fusil oil or benzol may remove the dirt quite easily, but caution is necessary in the application. Many organic solvents are highly inflammable and their use should be carefully supervised and regulated.

A fair trial of the frequent application of soap and water for cleaning lamps and reflectors will reveal a surprising increase of illumination and result in a verdict demanding proper maintenance of lighting equipment.

USE OF LAMPS IN REFRIGERATING ROOMS

A frequent question in the lighting of refrigeration rooms, such as meat coolers, cold-storage warehouses, etc., is the relative heating effect of vacuum and gas-filled lamps within such interiors. The fact that the vicinity of the gas-filled lamp is comparatively hot gives rise to the erroneous assumption that a gas-filled lamp will heat the interior of such a cold room to a greater extent than will a vacuum lamp of equal wattage. A refrigerator room, from its very nature, is usually constructed in such a maner that its walls are extremely well insulated to prevent the passage of heat and light through them. Therefore, the entire amount of heat and light energy emitted by an incandescent lamp in such a room is eventually absorbed by the walls of the room and taken up by the cooling system. A vacuum and a gas-filled lamp of equal wattage emit equal total amounts of energy (heat and light combined) Hence the effect of each of these lamps on the cooling system is exactly the same. A 100-watt gas-filled lamp completely enclosed in a refrigerator so that all of its energy is applied to melting ice, will melt 57 lb. of ice at 0 deg. cent. in 24 hours.

ALL-FROSTED LAMPS IN SEMI-INDIRECT BOWLS ELIMINATE CEILING SHADOWS

Many of the earlier indirect and semi-indirect bowls for office and home lighting were arranged to accommodate several small tungsten lamps. In these designs the problem of ceiling and wall shadows was somewhat unimportant as the light rays from each lamp tended to soften the shadows cast by the others. However, instead of one shadow from each chain or fixture part, there were as many shadows as there were lamps, and these multiple shadows though much subdued, were often sufficiently prominent to be undesirable. Of late, since one large gas-filled lamp is more efficient than several vacuum lamps and the fixture design is more simple if only one socket need be provided, practise has very definitely shifted to single lamp bowls, in which clear bulb lamps often create very objectionable shadows on the ceiling and walls. The use of all-frosted lamps in the ordinary open semi-indirect or indirect bowls will eliminate the ceiling shadows that stand out so prominently when clear lamps are used.

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The Pacific Coast Convention

AUGUST 8-11, 1922

The 11th Pacific Coast Convention of the A. I. E. E., held in Vancouver, B. C., August 8-11, was an entire success in regard to attendance, technical program and entertainment features. The total registration at the Convention was 235, including ladies. The retiring president, William McClellan, presided.

The Convention was called to order Tuesday at 10:00 a. m., and Lieut.-Governor Walter Cameron Nichol delivered an address of welcome which was responded to by President McClellan, who emphasized the present significance of the word "American", which now is recognized as embracing not only the people of the United States, but also the inhabitants of the great sister democracy on the North American continent. Vice-president O. B. Coldwell, the next speaker, referred to the vast opportunities of the electrical engineer in that part of the country where the population is scarce and the natural resources are abundant. The technical program was next taken up and the following papers were presented and discussed:

Power Development on the Colorado River and Its Relation to Irrigation and Flood Control, by O. C. Merrill, Secretary, Federal Power Commission, and *220-Kv. Transmission of the Southern California Edison Company and Some 220-Kv. Researches*, by R. J. C. Wood, Engineer, Southern California Edison Company.

At noon on Tuesday a luncheon for Institute officers and representatives of Sections was held at which various Institute matters were discussed. There was a considerable competition among Pacific Coast cities for the next year's convention and recommendation was finally made that it be held in San Francisco in 1923.

TUESDAY AFTERNOON

Tuesday afternoon was devoted to a 30-mile auto trip around Stanley Park, Marine Drive and Shaughnessy Heights, in which about 100 members and friends participated, and which was especially appreciated by visiting members.

TUESDAY EVENING

At the Tuesday evening session an interesting address was given by Vice-President G. Faccioli, Electrical Engineer, General Electric Company, Pittsfield, Mass., on *Little Stories of Engineering*, which portrayed numerous human interest features based upon extensive technical engineering experiences.

WEDNESDAY MORNING

The technical session on Wednesday morning was devoted to the general subject of high-tension insulators, and three papers were presented and discussed as follows: *An Over-Potential Test for Insulators*, by G. W. Lapp, Lapp Insulator Co., Inc., LeRoy, N. Y.; *Failure of Disk Insulators on High-Tension Transmission Lines*, by Harrison D. Panton, Carolina Power & Light Co., Raleigh, N. C., and *Tests and Investigations on Extra High-Tension Insulators*, by C. C. Farr, Professor of Physics, Canterbury College, University of New Zealand, and H. E. R. Philpott, Testing Engineer, Lake Coleridge Hydro-Electric Power Supply, Christchurch, N. Z.

Following the technical session, luncheon was served for all in attendance at the invitation of the local Section.

WEDNESDAY AFTERNOON

Immediately after luncheon a photograph of the Convention party was taken at the Provincial Courthouse, located in the block adjoining the Hotel Vancouver.

The technical session followed and was a continuation of the symposium on Technical Education, which was given at the Niagara Falls Convention. The following papers were read and discussed: *Conservation of Human Material*, by J. W. Upp, Manager, Switchboard Department, General Electric Company, Schenectady, N. Y., *Coordination of Professional Engineering and College Training*, by E. E. F. Creighton, Research Department, General Electric Company, Schenectady, N. Y.; *Training to Think Versus Gathering Information*, by T. Milton, Manager, Chicago Branch, Electric Storage Battery Co.; *Engineering Graduates in Business*, by L. A. Ferguson, Vice-President, Commonwealth Edison Co., Chicago, Ill.

A party of 48 ladies spent the afternoon at Capilano Canyon, which is about seven miles distant from Vancouver, and is reached by crossing the Burrard Inlet to North Vancouver. Tea was served at the Canyon View Hotel before returning to the city.

WEDNESDAY EVENING

The official Convention Dinner was held Wednesday evening in the Oval Room of the Hotel Vancouver, with over 150 in attendance. President McClellan was the principal speaker of the evening, and short addresses were also given by Mr. J. B. Fisken, of Spokane; Mr. C. C. Pratt, of Salt Lake City; Mr. R. M. Boykin, of Portland; and Mr. John R. Read, Chairman of the Vancouver Section.

THURSDAY MORNING

At the technical session Thursday morning three papers were considered, two being on the subject of transmission systems, as follows: *The Electrical Characteristics of Transmission Systems*, by H. B. Dwight, Electrical Engineer, Canadian Westinghouse Company, Limited, Hamilton, Ont., and *Graphic Methods for the Exact Solution of Transmission Lines*, by C. H. Holladay, Engineer, Southern California Edison Company, Los Angeles, Calif.; the third paper presented was entitled *Exciter Instability*, by R. E. Doherty, Designing Engineer, General Electric Company, Schenectady, N. Y.

THURSDAY AFTERNOON

Two addresses were delivered at the afternoon session on Thursday, one on the subject of *Research*, by C. E. Skinner, Assistant Director of Engineering, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa., the other on *Electric Propulsion of Battleships*, by Commander A. M. Charlton, U. S. S. *Tennessee*.

About forty ladies attended a matinee at the Capitol Theater as guests of the Convention on Thursday afternoon.

THURSDAY EVENING

A pictorial symposium of power plant comparisons was delivered on Thursday evening by R. J. C. Wood, Engineer of the Southern California Edison Co., and Joseph Mini, Jr., Engineer of the Pacific Gas & Electric Co.

FRIDAY MORNING

The final technical session of the convention was called to order Friday morning and the following papers were presented and discussed: *The Development of Telephotography*, by D. W. Isakson, Utah Power & Light Company; *Recent Conclusions Pertaining to Electrical Precipitation*, by W. A. Schmidt, President, Western Precipitation Co.; *Electrical Engineering Features of the Electrical Precipitation Process*, by G. H. Horne, Engineer, Western Precipitation Company; *Electrical Precipitation of Solids from Smelter Gases*, by R. B. Rathbun, Research Department, American Smelting & Refining Company.

FRIDAY AFTERNOON

On Friday afternoon the members and their friends at the Convention were the guests of the British Columbia Electric Railway Company, Limited, and were taken for a trip to the Lake Buntzen power houses of this company. These power houses, which are located on salt water, are reached by a very pretty trip of 20 miles up Burrard Inlet, the last portion of the journey being through the "North Arm" of the Inlet, which is quite characteristic of the many inlets on the North Pacific coast, and which are said to have their only counterpart in the Norwegian fjords.

SATURDAY MORNING

On Saturday, August 12th, some 15 members made a trip from Vancouver to Bellingham, Washington, where the U. S. S. *Tennessee* was in port and, as the guests of Lieutenant Commander A. M. Charlton were shown the various points of interest in connection with this electrically propelled battleship.

The Convention was thoroughly enjoyed by all in attendance who were loud in their praises of the entertainment and efficient services provided by the local committee. The personnel of the committee includes Mr. J. R. Read, Chairman, Mr. F. W. MacNeill, Secretary, and Messrs. C. N. Beebe, T. H. Crosby, J. Muirhead, L. B. Philpot, J. H. Fletcher, W. W. Fraser, Frank Sawford, A. Vilestrup and A. C. R. Yuill.

A. I. E. E. Directors' Meeting

The regular meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Tuesday, August 8, 1922.

There were present: President Frank B. Jewett, New York; Past-President A. W. Berresford, Milwaukee; Vice-Presidents N. W. Storer, Pittsburgh, and W. I. Slichter, New York; Managers L. E. Imlay, Niagara Falls, L. F. Morehouse, E. B. Craft, Harlan A. Pratt, New York, H. M. Hobart, Schenectady, and G. L. Knight, Brooklyn, N. Y., Secretary F. L. Hutchinson, New York.

Approval by the Finance Committee of monthly bills amounting to $22,298.90 was ratified.

A report of a meeting of the Board of Examiners held August 4 was presented and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners, the following action was taken upon pending applications: 21 Students were ordered enrolled; 103 applicants were admitted to the grade of Associate; 15 applicants were admitted to the grade of Member; 14 applicants were transferred to the grade of Member; 2 applicants were transferred to the grade of Fellow.

President Jewett announced the appointments of committees for the administrative year beginning August 1, 1922. (These committees are listed elsewhere in this issue.)

In accordance with the by-laws of the Edison Medal Committee, the Board confirmed the appointment by the President of Messrs. Gano Dunn, F. A. Scheffler, and W. R. Whitney as members of the Edison Medal Committee for a term of five years, and elected to the Committee from its own membership, for a term of two years, Messrs. E. B. Craft, G. Faccioli, and William McClellan.

The following men were appointed as representatives of the Institute on the American Engineering Council of the Federated American Engineering Societies for a term of two years commencing January 1, 1923: C. A. Adams, C. G. Adsit, F. L. Hutchison, Frank B. Jewett, Charles F. Scott, C. E. Skinner, L. B. Stillwell, Calvert Townley. Six of these were appointed (or reappointed) to succeed the six representatives of the Institute whose terms will expire on December 31, 1922; the remaining two are additional representatives to which the Institute is entitled by reason of its increase in membership. (This makes a total of fourteen A. I. E. E. representatives on the American Engineering Council; the terms of the other six expire on December 31, 1923).

An invitation, received through the Brazilian Embassy at Washington, for the Institute to participate in an International Congress of Engineers to be held at Rio de Janeiro, September 7-30, 1922, in connection with the Brazilian Centennial Exposition, was accepted and the President was authorized to appoint delegates to the Congress.

A communication from the Chairman of a Committee on National Engineering Museum was presented, requesting the cooperation of the Institute in a movement to establish an Engineering Museum. The President was authorized to appoint representatives to confer with the Committee.

An invitation to be represented at a conference on Metric System to be held at the Carnegie Institute of Technology, Pittsburgh, September 6, was accepted and the President was authorized to appoint a delegate.

Reference to other matters discussed may be found in this and future issues of the JOURNAL under suitable headings.

Standards Committee of A. I. E. E.

For several months the Standards Committee and the Directors of the A. I. E. E. have had under consideration the formulation of a plan of organization and procedure under which the Committee could function to better advantage. The matter was again considered at the meeting of the Board of Directors held June 29, 1922, and the following extract from the minutes of the meeting indicates the action that was taken:

EXPLANATION

The object sought is the establishment of a working organization and procedure for the Standards Committee, which shall permit operation under the resolution of May 20th, 1921, without requiring the actual membership of non-Institute members in the Standards Committee.

To that end there is constituted a Standards Committee, consisting primarily of eight members and a chairman appointed by the President at the beginning of the Institute year. This Committee organizes the work of the Standards Committee by the appointment of working committees, one for each active subject, the chairman of such working committees to be nominated by the Chairman of the Standards Committee and appointed by the President. Such chairmen shall be either

Associates, Members or Fellows of the Institute, and upon appointment become members of the Standards Committee.

The personnel of the working committees are not members of the Standards Committee and should be those best constituted to carry on the work whether Institute members or not. They may be chosen so as to comply with the requirements for a Sectional Committee of the A. E. S. C. Such working committees can endure only during the life of the appointing power but may be continued by reappointment from period to period. Their life definitely and automatically terminates upon completion of the work assigned to them.

To the above ends the following resolution was adopted.

RESOLVED:—that the organization, the function and the procedure of the Standards Committee be as follows:

ORGANIZATION

(1) The Standards Committee shall consist of a Chairman and eight members appointed by the President, together with the Chairman of the working committees and of delegations hereinafter provided.

(2) No person not a member of the Institute, either Associate, Member or Fellow, shall be a member of the Standards Committee, but such persons may be members of working committees of the Standards Committee.

(3) The Chairman of the Standards Committee shall nominate to the President for appointment the Chairman and members of the following:

(a) Subcommittees for the purpose of facilitating the general administrative work of the Standards Committee, all of whose members shall be appointed from the Standards Committee.

(b) Working committees on specific standards when actual work on such standard is contemplated or in process. The Chairmen of such committees shall be Institute members and such committees may be reappointed to extend beyond the duration of the appointing power but shall automatically be terminated by the completion of the work assigned.

(c) Delegations to serve with the delegations from other organizations, the Chairmen and all members to be members of the Institute.

(4) The Standards Committee may at its discretion appoint from its membership an executive committee.

(5) The Chairman of the Standards Committee shall appoint a Secretary.

FUNCTION

(6) By-law Section 28 sets forth the function of the Standards Committee.

"The Standards Committee shall consider and investigate all matters relating to units and standards appertaining to or applicable in electrical engineering and in the allied arts and sciences. The committee shall make reports and recommendations to the Board of Directors for action thereon."

(7) In reading Section 28 of the By-laws of the Institute, the Standards Committee, to determine its activities, shall consider the increasing extensiveness of electrical engineering as well as the important position which kindred organizations have attained in relation to Standards, and as in the past, shall give particular attention to definitions, limits, tests and methods of tests.

PROCEDURE

(8) Upon the proposal to formulate a new standard or to modify an existing one, the Standards Committee shall consider whether such standard is (a) within the Institute's direct function (b) within the joint function of the institute and other organizations (c) wholly within the field of other organizations, and shall communicate its opinion to the A. E. S. C. and request action thereon, and upon receipt of decision from the A. E. S. C. shall take appropriate steps hereunder.

(9) Nothing contained herein shall prevent the Standards Committee from undertaking the formulation of an "Institute Standard" without concurrence of the A. E. S. C.

(10) The Standards Committee, at a convenient time, shall present standards which it has approved as "Institute Standards" to the Board of Directors for adoption.

(11) The Standards Committee shall have power in all matters relating to Standards not inconsistent with these resolutions, the Constitution and By-laws of the Institute, and the general powers of the Board of Directors.

In accordance with the above action, the Standards Committee for the new administrative year beginning August 1 was appointed by President Jewett at the Directors' meeting held August 8. The personnel of the committee is as follows: Messrs. Harold Pender (Chairman), W. A. Del Mar, H. A. Lardner, A. M. MacCutcheon, J. F. Meyer, F. D. Newbury, F. L. Rhodes, L. T. Robinson, and R. F. Schuchardt.

President McClellan Visits Western Sections

During the latter part of July, President William McClellan started from New York on a trip to the Pacific Coast for the purpose of visiting several of the Institute Sections, and in particular to attend the Pacific Coast Convention of the Institute which was held in Vancouver, August 8-11.

Dr. McClellan addressed meetings in St. Paul, July 31st; Spokane, August 3rd; Seattle, August 4th; Portland, August 5th; Vancouver, August 8-9, Salt Lake City, August 12th; Denver, August 14th; and Kansas City, August 15th.

These meetings, which in each case had been arranged by the local Section of the Institute, were attended not only by members of the Institute, but by much larger groups of engineers and business men to whom invitations had been extended by the Institute Sections.

Dr. McClellan's talks were not limited to Institute affairs, but he also discussed many topics relating to engineering economics, with particular reference to the future development of the electrical industry and the nation.

In addition to the meetings referred to, Dr. McClellan's trip afforded much appreciated opportunities of discussing with the various Institute officers and executive committees the scope of the Institute's activities, and opportunities for further development and usefulness of the local Sections to the membership and the profession generally.

Engineering Joint Council in England

INSTITUTIONS COOPERATING

It is announced that proposals for closer cooperation amongst the leading engineering Institutions in Great Britain which have recently been under consideration, have now received the approval of the institutions whose representatives met in conference, namely, the Institution of Civil Engineers, Institution of Mechanical Engineers, Institution of Naval Architects and Institution of Electrical Engineers; and that an Engineering Joint Council composed of representatives of these bodies has been formed.

The objects of the Joint Council will be, among others, to improve the status of engineers, to secure the better utilization of their services in the country's interests, and the appointment of properly qualified individuals to responsible engineering positions, and to prevent the unnecessary duplication of activities. At a later stage the number of bodies represented on the Joint Council may be increased.

International Engineering Congress in Brazil

As announced in the August issue of the JOURNAL, an International Congress of Engineers is to be held at Rio de Janeiro Brazil, during the Brazilian Centennial Exposition. The dates of the Congress are September 7-30, and the Exposition will continue until March 31, 1923.

The American National Societies of Civil, Mining, Mechanical and Electrical Engineers were invited by the Brazilian Embassy to participate in the Congress, which is being organized by the Club de Engenharia of Rio de Janeiro.

Upon receipt of the invitation during July, each of the four National Societies named above appointed representatives upon a joint committee to arrange for the participation of the American Societies in the Congress by the presentation of technical papers and otherwise. The A. I. E. E. representatives on this committee are: Messrs. Maurice Coster, F. L. Hutchinson and Percy H. Thomas. Mr. Vern L. Havens, Editor of *Ingenieria Internacional*, was elected Chairman of the joint committee, and upon his departure for Brazil a few weeks ago, he was succeeded in the chairmanship by Mr. Percy H. Thomas. A corresponding committee has been organized at Rio de Janeiro under the chairmanship of Mr. C. H. Crawford, and Mr. Havens will act as a liaison officer between the two committees.

The joint committee has been actively at work for some weeks past, and has arranged for the presentation of a number of technical papers upon various phases of engineering, and most of the manuscripts have already been forwarded to Brazil.

The invitation to participate was formally accepted by the A. I. E. E. at the August meeting of its Board of Directors, and President Jewett was authorized to appoint delegates to the Congress. The other Societies named have also taken similar action.

Eight delegates of the A. I. E. E. have been appointed, as follows: Messrs. A. W. K. Billings, F. J. W. Luck, Carroll M. Mauseau, J. H. Payne, Calvin W. Rice, F. H. Shepard, Edwin A. Sturgis, and William V. Van Dyck.

A. I. E. E. Transactions

After completing the distribution of the A. I. E. E. TRANSACTIONS for 1921, there remains a surplus, from which a limited number of copies can be supplied. Members who have not previously ordered the 1921 volume of TRANSACTIONS can obtain these copies while they last by placing an order for them at Institute headquarters. The price of the 1921 TRANSACTIONS is $3.00, and as the number of copies available is small, it will be necessary to place orders promptly.

Members of the Institute are also reminded that the edition to be printed of the 1922 TRANSACTIONS will be determined by the number of subscriptions received in advance. The cost of this volume, as stated in previous notices, will be $2.00. Members who desire a copy and who have not already subscribed are requested to advise the Secretary at Institute headquarters promptly.

Chemical Exposition at the Grand Central Palace

The 1922 National Exposition of Chemical Industries will be held at the Grand Central Palace, New York City, during the week of September 11th-16th. Chemical raw materials, machinery, and equipment produced by more than 400 American Manufacturers will be exhibited for the consumers. The show rooms will occupy four floors. Special features will be devices for industrial fire and explosion prevention and for fuel and power efficiency.

Scientific discussions will be held by various associated chemical organizations every afternoon at the auditorium of the Grand Central Palace. The speakers at the opening session will be Wayne B. Wheeler, Dr. Charles Herty and others. The programs of the succeeding days will be directed by the Synthetic Chemical Manufacturers of the United States, the Technical Association of the Pulp and Paper Industry, the Technical Photographic and Microscopical Society, and the American Ceramic Society. On the 15th there will be a Symposium on Standardization. Herbert Hoover, Secretary of Commerce, will speak at the annual dinner of the Salesmen's Association of the American Chemical Industry.

Each afternoon and evening moving pictures will be shown of a variety of chemical processes and devices in operation at manufacturing plants. The speakers will include representative men from a wide field of chemical industry. One of the few women taking part in the Exposition will be Miss Lida Hofford, Director of the General Federation of Women's Clubs, Washington, D. C., who will speak on "Women's Interest in Chemistry in America."

Machine Tool Exhibition

The Second Annual Machine Tool Exhibition to be held under the auspices of the New Haven Branch of the American Society of Mechanical Engineers and the Dept. of Mechanical Engineering of Yale University will take place on September 21, 22 and 23 in Mason Laboratory, New Haven, Conn. Exhibits of the very latest developments in machine tool practise, will be accompanied each evening by instructive papers by leading authorities. As the purpose of the exhibition is the stimulation of industry with a view towards hastening restoration of prosperity, no charge will be made for exhibition space or for admission of spectators. For detailed information address H. R. Westcott, 207 Orange Street, New Haven, Conn.

Meeting of Radio Engineers

SEPTEMBER 6, 1922

The next meeting of the Institute of Radio Engineers will be held on the evening of Wednesday, September 6th, 1922, at 8:15 P. M., in the Engineering Societies Building, 29 West 39th Street, New York City.

A paper on "Vacuum Tubes" will be presented by Mr. F. S. McCullough of the Westinghouse Electric and Manufacturing Company. Some interesting aspects of the production and use of vacuum tubes will be presented.

Members of the A. I. E. E. are cordially invited to attend.

PERSONAL MENTION

M. L. HARNED, formerly Research Engineer with the Union Gas & Electric Company, Cincinnati, Ohio, is now Engineer with Stewart & Company, Cincinnati, Ohio.

F. S. HUNTING resigned from the General Electric Co., Fort Wayne, Ind., on July 1st, to become President and General Manager of The Robbins & Myers Company, Springfield, Ohio.

TYLER G. PRICE has severed his connection with the San Joaquin Light & Power Corporation, Fresno, Cal., and is now associated with the Dodge Institute, Valparaiso, Ind.

GEORGE BROCK, formerly Electrical Draftsman for Sargent & Lundy Co., Chicago, Ill., has accepted a similar position with the Western Electric Co., Hawthorne, Ill.

L. R. BERKELY, formerly with the National Carbon Company, Cleveland, Ohio, is now associated with the Rail Welding and Bonding Company, Cleveland, Ohio.

JAMES C. F. SHAFER resigned as Vice President of the Boldt Construction Company last February, and is now operating, as constructor of complete industrial and commercial plants, at 400 Erie Building, Cleveland, Ohio.

Charles F. de Mey has severed his connection with the Hudson Coal Company, Scranton, Pa., and has become associated with the Central Hudson Gas & Electric Company, Poughkeepsie, N. Y.

W. F. Davison has left his position with the University of Michigan to accept a position as Director of Engineering Investigation with the Brooklyn Edison Company, 360 Pearl St., Brooklyn, N. Y.

Fred J. Singer has resigned as Instructor of Electrical Engineering at the University of Wisconsin, and is now in the Department of Development and Research of the American Telephone & Telegraph Company, New York, N.Y.

H. R. Woodrow, formerly connected with the Westinghouse Electric & Manufacturing Co., New York, N. Y., is now associated with the Brooklyn Edison Company, Brooklyn, N. Y., as Assistant Electrical Engineer.

F. J. Gleiss has resigned his position as Oakland District Engineer with the Great Western Power Co., San Francisco, Cal., and is now connected with the Western Sales & Engineering Co., Oakland. Cal.

N. J. Mittenthal has severed his connection with the International General Electric Company, Schenectady, N. Y. to become Sales Engineer with the Pacific States Electric Co., San Francisco, Cal.

B. L. Conley resigned as Instructor in Electrical Engineering at Case School of Applied Science, Cleveland, Ohio, and is now Electrical Engineer, of the Hoover Suction Sweeper Company, North Canton, Ohio.

T. J. Jendrasiak, until recently with the General Electric Company, Schenectady, N. Y., Testing Department, has been transferred to the Buffalo Office of the General Electric Company, Construction Department.

R. Philip Hart resigned from his position as Head of the Standardization Laboratory of the Hartford Electric Light Company, Hartford, Conn., during March 1922, and has been made Manager of the Cazenovia Electric Co., the central station company of Cazenovia, N. Y.

Frank T. Forster, formerly Electrical Engineer with the United Theater Equipment Corp., New York, N. Y., is at the present time temporarily employed by Mr. J. H. Hallberg, manufacturer of electrical specialties, as radio engineer, to investigate radio problems.

E. Burwell Ilyus left the employ of the Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., on August 1st, 1922, to accept the position of Assistant Engineer in the Substation Division of the Engineering Department of the Duquesne Light Company, Pittsburgh, Pa.

H. J. Burgess has accepted the position of electrical engineer of H. E. Crook Co., Inc., contracting engineers, Baltimore,Md. Mr. Burgess formerly was a member of the Industrial Power Department, The Consolidated Gas, Electric Light and Power Company, of Baltimore.

John L. Niesse was appointed Telegraph and Telephone Engineer on August 1st, of the New York Central Lines, with headquarters at 466 Lexington Avenue, New York, his previous position being Telegraph and Telephone Engineer, Big Four Railway, Indianapolis, Ind.

Stanley Rhoads, Telegraph and Telephone Engineer, New York Central Lines, New York, has left railroad service and is now with the New York Telephone Co., New York, as an Equipment Engineer in the Plant Department of the Manhattan, Bronx and Westchester Division.

H. E. Dalzell has resigned his position as Chief Mechanical and Electrical Engineer of the Southern Railway of Peru after fifteen years service in the tropics. He is taking eight months' holiday and will take advantage of this time to place his several inventions on the market. He expects to take up an appointment on the East Coast of South America in the Spring.

H. R. Eilertsen has resigned as Electrical Engineer of R. Hoe & Company, New York, N. Y., and is now Sales Engineer with the Cutler Hammer Mfg. Co., Printing Equipment Department, New York, N. Y. In pursuing this work he will specialize in the electrical problems associated with the small accessory machinery used in the printing industry.

Howard D. Matthews has terminated his connection with the Milwaukee School of Engineering, where he has been head of the Department of Electrical Design for the last four years, and is now in the Engineering department of the Westinghouse Electric & Manufacturing Company at East Pittsburgh, Pa. Before going to Milwaukee Mr. Matthews was identified for ten years with the General Electric Company at Schenectady, N. Y., as a designing engineer.

A. H. Anderson recently returned from Haiti, where he acted as electrical engineer with the Haitian American Sugar Co., and assistant superintendent of the Port au Prince Electric Light Co. Prior to his work in Haiti he spent about five years in South America, two years on the west coast with the Chile Copper Co., and the balance of that time with the Armour interests as electrical engineer in charge of construction, in the building of packing plants, eighteen months being devoted to work in Patagonia.

A. E. Kennelly, Professor of Electrical Engineering at Harvard University and the Massachusetts Institute of Technology, has been awarded the Cross of the Legion of Honor for distinguished services as exchange professor in engineering to the French Republic. Dr. Kennelly was the first exchange professor sent to France from America under the scheme of regular annual exchange of professors in engineering and applied science, inaugurated last fall between the French University Administration and seven American institutions.

R. A. Lundquist, Chief of the Electrical Equipment Division, Department of Commerce, sailed on August 10th from New York for a short trip through England, Sweden, and Germany, to study the electrical development in those countries. He is especially interested in the superpower schemes in Sweden and England, and is to give close attention to the rural development in the former country. He also will study the domestic appliance possibilities for American manufacturers in England. This survey of electrical conditions will cover a period of about three months.

Obituary

Frank W. Frueauff, junior member of the firm of Henry L. Doherty and vice-president of the Cities Service Company, died suddenly on Monday, July 31, at his home in New York City. He was one of the outstanding figures in the electric light and power world.

Mr. Frueauff was born on March 29, 1874, in Columbia, Pa. His parents moved to Denver, Colorado, where he went to school, and afterward entered the employ of the Denver Consolidated Electric Company, where he remained until it was bought out by the Henry L. Doherty Company. With this concern he rose rapidly, becoming vice-president, general manager and president. As director in 141 corporations he served all parts of the country, and was promoter of the sale of securities to customers.

Mr. Frueauff was president of the National Electric Light Association for 1909-1910, president of the National Commercial Gas Association and of the Colorado Light, Power and Railway Association, an Associate of the American Institute of Electrical Engineers and a member of the Illuminating Engineering Society.

Alexander Graham Bell, the inventor of the telephone, died at his summer home near Baddeck, Nova Scotia, on August 2. Although he had been in failing health for some time, he had not been confined to his bed, and his death was unexpected.

Dr. Bell was born in Edinburgh on March 3, 1847. His father and his grandfather were both teachers of vocal physiology and the laws of speech, so that Bell from the very early years was interested in all matters pertaining to the human voice. At fourteen years of age he came to London, and was instructed by his grandfather in elocution and phonetics. He retured to Edinburgh to attend courses at the University. He was later, while still quite a young man, assistant to his father who had obtained a post as lecturer in elocution at University College, London. It was at this time that Bell met Wheatstone and Ellis and became interested in Helmholtz's work on the electro-magnetic control of tuning forks.

In 1870, the Bell family emigrated to Canada and in the following year Alexander, at the age of 24, obtained an appointment in Boston as instructor to deaf and dumb children. It was during the next few years in Boston that his work leading to the invention of the telephone was done. The story of "How Bell Invented the Telephone" was given in great detail by his former assistant Thomas A. Watson, at the ceremony of the presentation of the Edison Medal to Dr. Bell in 1915, and is published in the A. I. E. E. Transactions, Vol. XXXIV, 1915.

Although Dr. Bell's fame rests principally upon his work on the telephone he did much other important scientific work and his scientific interests were widely varied in character. He made many researches in connection with the transmission of sound by means of light by utilizing the change in resistance of selenium when varying light falls on it. Dr. Bell transmitted speech a distance of 213 m. by a beam of light from an instrument placed on the top of the Franklin school house in Washington. He found that articulate speech could be reproduced by the oxy-hydrogen light and even by a beam from a kerosene lamp.

Dr. Bell was also interested in mechanical flight and constructed several aeroplanes. The second, named Cygnet II, was tested in Nova Scotia in the year 1909. It was largely built of bamboo, and measured some 50 ft. from wing tip to wing tip. It was fitted with a 35-h. p. motor driving the single propeller through a chain. Cygnet II was built up with an enormous number of tetrahedral cells disposed over a slightly inclined plane. The work on this machine followed fairly successful flights of an earlier machine, Cygnet I, which was built as a kite on the same lines.

Dr. Bell was the recipient of many honors from governments and learned societies including the decoration of the Legion of Honor from France, the Albert medal of the society of Arts of London, the gold medal of the Royal Society of England, the Elliott Cresson medal of the Franklin Institute and the Edison medal of the American Institute of Electrical Engineers. The French Academy gave him the Volta prize of 50,000 francs. He had honorary degrees from several universities including Harvard, the University of Illinois, and Heidelberg. He was elected vice-president of the A. I. E. E. in 1884 and served as President in 1891-1892. The Board of Directors of the A. I. E. E. adopted the following Memorial August 8, 1922:

WHEREAS the Board of Directors of the American Institute of Electrical Engineers has learned with deep sorrow of the death on August 2, 1922, of Alexander Graham Bell,

RESOLVED that as a tribute to his memory, this minute be inscribed in the records: In the death of Alexander Graham Bell, the inventor of the telephone, the world has suffered the loss of one of its great benefactors. His was a life dedicated to the service of mankind. By his early researches in acoustics, he learned how to teach the dumb to talk, and thus restored to the afflicted their heritage of speech.

By his deeper researches in physics, he discovered how to transmit by electricity to distant places the tones of the human voice in the form of articulate speech. He was the first to provide the apparatus to do this marvel; he was the first to speak through the electric speaking telephone; and his voice was the first to be heard in the telephone receiver. Based upon his invention, vast telephone systems of intercommunication have been developed, extending the spoken word among the peoples of all the nations.

In recognition of his priceless service to electrical engineering, the American Institute of Electrical Engineers many years ago conferred upon him the honor of its highest office by electing him to be its President; and again, in recognition of his acheivements, bestowed upon him the Edison Gold Medal for his distinguished attainments in electrical engineering, electrical science, and the electrical arts. And now, at the time of his death, the members of the Board of Directors record their realization of the grievous loss to the Institute, to the engineering profession, and to the whole world, and express their deep and heartfelt sympathy to his wife and to the other members of his family in their bereavement.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES (JULY 1-31, 1922)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Beleuchtung der Bahnhöfe und der Bahnhofshochbauten.

Von Richard Sarre. Leipzig, Wilhelm Engelman, 1922. (Handbuc der Ingenieurwissenschaften, 5. Teil, 5. Band) 300 pp., illus., 10 x 7 in. cloth. 154 Mk.

The primary object is to provide a discussion upon the principles and systems of lighting railway stations and railway office buildings. But since every existing method of lighting has been used for these purposes and since the principles of artificial lighting are of general application, the book is in reality a concise survey of methods of illumination and of the laws governing their use.

Chemical Technology and Analysis of Oils, Fats and Waxes. Vol. 2.

By J. Lewkowitsch. Sixth edition, revised by G. H. Warburton. Lond., Macmillan and Co., Ltd., 1922. 959 pp., illus., tables, 9 x 6 in., cloth. $14.00.

The second volume of the new edition of this popular treatise is concerned with methods of preparing, refining and examining the natural oils, fats and waxes, and of detecting adulterations. It is an exhaustive summary of present knowledge upon its

subject, containing detailed chemical and physical data upon all known oils. This edition has been carefully revised.

LES COLLOIDES.

Par J. Duclaux. Paris, Gauthier-Villars et Cie, 1922. (Actualités scientifiques). 305 pp., 7 x 5 in., paper. 10 fr.

This work does not purport to be encyclopedic. It is, rather, a concise statement of chosen facts woven into a coherent account, from a single point of view, with useless details and superimposed theories avoided. Certain modifications have been made in the new edition. The author is Director of the Laboratory of the Pasteur Institute.

MATHEMATICAL THEORY OF PROBABILITIES.

By Arne Fisher. Second edition, enlarged. N. Y., The Macmillan Co., 1922. 289 pp., 9 x 6 in., cloth. $5.00.

The author's aim has been to treat all the modern researches upon this important branch of applied mathematics from a common point of view, based upon the mathematical principles laid down by Laplace, and to present a theory of probabilities as developed in recent years of value to the practical statistician, the actuary, the engineer and the biologist, as well as students of mathematics.

The second edition is extended to nearly twice its original size by added chapters on frequency functions and their applications. Mr. M. C. Rorty contributes an introductory note indicating some of the practical applications of the theory of probabilties to business problems.

STEAM TURBINES.

By William J. Goudie. Second edition. Lond. and N. Y. Longmans, Green and Co., 1922. 804 pp., plates, diagrs., illus. 9 x 6 in., cloth. $10.00.

This book has been written primarily to suit the requirements of engineering students, but the author hopes that the methods of calculation outlined in it will be useful also to engineers engaged in the design or operation of steam turbines.

The first portion of the text is devoted to detailed descriptions of commercial representatives of the various types now on the market. The second portion treats what may be termed the "technical" part of the subject; nozzles, blading, rotors, gearing, steam consumption, proportions, governing, etc.

This edition has been completely rewritten and enlarged.

UBER DIE FESTIGKEITSBERECHNUNG VON SCHIEBETOREN UND ÄHNLICHEN BAUWERKEN,

Von Adolf Eggenschwyler. Leipzig, H. A. Ludwig Degener, 1921. 148 pp., 9 x 6 in., paper.

This monograph discusses the problems in statics involved in the design of sliding sluice-gates, floating docks, movable weirs and similar hydraulic structures composed of steel plates and frames. The statical problems that they present are, according to the author, midway between those of bridge building and shipbuilding; and have until now been much neglected. In consequence, the calculations of designers have been based on false assumptions, which have frequently led to an extravagant use of material and to lack of the necessary strength.

Past Section Meetings

Cleveland.—May 23, 1922, Electrical League Rooms. Annual Dinner and election of officers as follows: Chairman, L. D. Bale; Secretary-Treasurer, Chester L. Dows; Executive Committee, R. P. Bunyan, F. L. Sessions, Austin M. Lloyd. The meeting was addressed by President McClellan of the A. I. E. E., who outlined the aims and functions of the Institute in a very entertaining manner. He laid particular stress on the importance of discussion of papers at Section meetings. Attendance 50.

Denver.—August 14, 1922, Metropole Hotel. Luncheon meeting in honor of retiring President of the Institute, William McClellan. Dr. McClellan talked on the subject of "Transportation and Power," and all present felt that they had received a very important message. Attendance 76.

Panama.—July 29, 1922, Hotel Central, Panama. Annual Meeting and election of officers as follows: Chairman, F. B. Coyle; Vice-Chairman, A. C. Garlington; Secretary-Treasurer, M. P. Benninger; Executive Committee, J. C. Myrick, W. L. Hersh, R. D. Prescott. Attendance 15.

Springfield, Mass.—July 21, 1922, Chamber of Commerce Rooms. Organization meeting and election of officers as follows: Chairman, W. A. Dick; Vice-Chairman, John M. Newton; Secretary-Treasurer, J. Frank Murray; Executive Committee, foregoing officers together with Messrs. Lorenzo J. Scott and L. W. Rosenthal.

Book Reviews

RADIO PHONE RECEIVING.

By Erich Hausmann, Alfred N. Goldsmith, L. A. Hazeltine, J. V. L. Hogan, and J. H. Morecroft. New York, D. Van Nostrand Company, 1922, 190 pages, 4½ x 7 in., cloth. $1.50 net.

This is an excellent handbook on Broadcast Radiophone reception, by a group of prominent radio engineers, written with a view to explaining in plain terminology the mechanism of radiophone transmission and reception. In a semi-technical, but authoritative manner, the various chapters deal with the tuning of circuits; reception with crystal detector; the vacuum tube; radio amplifiers; regenerative and heterodyne reception, and radio broadcasting. The circuit diagrams employed throughout the book are those used in the most highly developed radio installations.

STANDARD LIGHTING WITH INCANDESCENT LAMPS.

By H. C. Cushing, Jr., New York. 272 pages, 240 illustrations, 55 tables, Flexible Leatherette. $3.00.

The book is unique in that it combines, for the first time, the recommended practises of all the leading illuminating engineers of the lamp manufacturers. Credit is given to seventeen such contributors.

The book contains the most complete treatise on the various phases of incandescent lighting practise ever presented in one volume. As such, there is perhaps some lack or unity in the treatment of the various topics.

Though intended for use as a text and reference book in the Electrify America movement, and indorsed by the Lighting Department of the Joint Committee, the subject is treated from the engineering rather than a commercial viewpoint.

The *Transactions* of the Illuminating Engineering Society and the bulletins of lamp maufacturers have been freely drawn on.

The purpose of the book is to educate the trade as to the importance of applying good lighting pratice. It also discusses the various methods of lighting. Being confined to one type of illuminant, definite suggestions can be briefly made.

Three chapters are devoted to general questions under the titles respectively of "Illumination Fundamentals," Illumination Design Data" and "Maintenance of the Lighting System."

The main portion of the book is devoted to specific classes of lighting as follows: Stores and show windows, industries, office buildings and drafting rooms, schools, residences, churches, public buildings, hospitals and dental offices, floor lighting applications, outdoor sports, indoor recreations, streets, signs.

The industrial lighting code of the Illuminating Engineering Society, recently adopted as an American Engineering Standard, is reproduced.

Addresses Wanted

1.—R. R. Batcher, 179 Marcy Ave., Brooklyn, N. Y.

2.—G. E. Bliziotis, 284 Market Street, Newark, N. J.

3.—Ricardo S. Bravo, Jr., 621 South Flores St., San Antonio, Texas.

4.—E. J. Condon, Jr., Minn. Electric Light & Power Co., Elks Bldg., Bemidji, Minn.

5.—J. Allen Fitz, 19 Fort Green Place, Brooklyn, N. Y.

6.—Arthur S. Howard, 2735 South Alder St., Philadelphia, Pa.

7.—Carl Irving, Box 675, Portersville, Cal.

8.—J. M. Kite, Guaranty Co. of New York, 140 Broadway, New York, N. Y.

9.—Gody Krusy, 16 Elizabeth Ave., Newark, N. J.

10.—H. F. Pippenger, 4647 Kenmore Ave., Chicago, Ill.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

RADIO ENGINEER for large electrical manufacturing company. Should be technical college graduate in electrical engineering, with experience in experimental radio development problems involving both transmitting and receiving. None but high grade development engineers need apply. Application by letter stating age, education and experience. Salary not stated. Location, Pa., V-1402.

HIGH CLASS ELECTRICAL SALES REPRESENTATIVES for reliable concern manufacturing carbon, graphite, electro-graphitic and metallic brushes for motors and generators, also general line of carbon specialties. Exclusive rights given to each of territories on liberal straight commission sales proposition. Specify in detail past engineering and sales experience. Territories Chicago vicinity, St. Louis, Birmingham, Washington D. C. and San Francisco. Headquarters, New York. V-2184.

CHEMICAL ENGINEER who has had actual experience in putting up naphthalene plants. Application by letter. Salary not stated. Location, New York City. V-1627.

SALES ENGINEER. Young single man having practical experience with detail electrical switchboard apparatus, such as Circuit Breakers and Instruments. Sales experience not necessary. State age, experience and salary expected. Location, Philadelphia territory. V-1683.

DESIGNER, with experience on carbon circuit breakers and other control devices. Technical man preferred. Application by letter stating age, experience and salary expected. Salary not stated. Location, Pa. V-1713.

SALES ENGINEER & DISTRICT MANAGER. Manufacturer of Conveying machinery, has unusually attractive opening for the *right man.* Must be well experienced, preferably with conveying equip., have good record and be able to get results. State full particulars, of experience, references, age, volume of sales and salary expected. Replies will be held strictly confidential and personal interview will be arranged by manufacturer. V-1727.

POSITION OPEN requiring several years experience on design of switchboards and substations. Apply with detail statement of experience and attach small photograph. Electrical engineering graduates only. V-1747.

PHYSICS INSTRUCTOR to start work Sept. 1st. Only two classes of men considered, those who have had teaching experience and expect to continue in profession, and those who have had good engineering training and engineering experience, but who plan definitely to go into teaching to stay. Takes at least two years to break even a good man in on work, and it is impossible that we should knowingly employ a man who does not take teaching seriously. Application by letter. Location, North East. V-1755.

TECHNICAL GRADUATE with considerable designing experience. Major work is of a mechanical nature on stationary structure involving practically no moving parts. Electrical knowledge and knowledge of transformer construction advantageous, but after all, it is fundamental mechanical knowledge that is most essential. Experience in tank construction and in structures involving rolled plates and shapes also desirable. A great deal of electric and autogenous welding is done on work involved, and here again, experience will assist him. Experience in standardizing essential. Main functions will be to gradually polish up desirable standards and assist in selling the idea of sticking to these standards. Application by letter. Salary not stated. Location, Pa. V-1761.

ELECTRICAL MANUFACTURING PLANT offers apprenticeship course for boys 13-17 who possess mathematical ability. Will be given courses in calculus, mechanical and electrical theory, chemical shop work, etc. Half time will be spent in commercial work which will be paid for. Application by letter. Salary not stated. Location, Mass. V-1744.

PRACTICAL WORKING MASTER MECHANIC, aggressive personality to supervise candy factory. Knowledge of German desirable but not essential. Application by letter. Location, New York City. V-1782.

ELECTRICAL or MECHANICAL ENGINEER who has also had sales organization experience, to be given charge organizing sales of farm electric light and power plants. Application by letter. Salary not stated. Location, Central West. V-1796.

ASSISTANT SUPERINTENDENT of Power for textile mill for supervision of modern 4500 kw. plant equipped with Edgemoor boilers, G. E. turbines and Wheeler feed water evaporators. Also to supervise 2200 volt overhead distribution, induction motors, mill and residence lighting and automatic telephone system. Must be in good health to stand tropical climate. A single man is desired under 30 years of age. Furnished quarters and good salary. Application by letter. Location, India. V-1803.

ELECTRICAL DRAFTSMAN, exp. in Power House Substation and Switchboard Design and layout. Application by letter stating education, experience and salary expected. Send photograph if possible. Location, Ill. V-1829.

TRANSFORMER DESIGNING ENGINEER with well known British firm of electrical engineers. Must have first class experience in design and manufacturing of large high tension transformers. Application by letter giving full particulars of experience. Salary not stated. Location, England. V-1830.

ENGINEER who can handle elevation work on locomotives, and who would be competent to order materials, and handle design of locomotive while going through the shop. Application by letter. Salary not stated. Location, Ohio. V-1839.

SALES ENGINEER to place electrical supplies and obtain construction jobs. Application in person. Good salary for right man. Location, N. Eastern U. S. V-1843.

INSTRUCTOR in experimental engineering. Will be expected to teach mechanical laboratory work, some classes in elementary steam power plants and have a small amount of office work to look after. Want a man who has been out of school a year or two and preferably one who has worked in a power plant or similar line of work. 1922 graduate might be considered. Application by letter. Location, South. V-1855.

CHIEF ENGINEER for manufacturers of conveying machinery. Chief engineer or chief draftsman, well experienced in layout construction and details of conveying machinery of various types. Capable of taking complete charge of drafting dept. Unusual opportunity offered to right man. Personal interview will be arranged. Give experience, age and salary expected. Application by letter. Location, Missouri. V-1856.

ENGINEER experienced in exporting line. Must understand Spanish shipping documents. Must know trade characteristics of cotton piece goods. Application in person., Location N. Y. C. V-1859.

ELECTRICAL ENGINEER. Graduate with few years experience to handle sales, transmission and distributing systems. Application in person. Location, Canada. V-1870.

INSTRUCTOR in heat engineering and steam laboratory in mechanical engineering department. Young technical graduate with some teaching experience desired. Location, Pa. Application by letter. V-1871.

ELECTRICAL ENGINEERS (2) as sales engineers in machinery company. Should be single and have practical shop experience, and one or two years office experience preferably in General Electric Company. Preference given to men who speak Spanish. Should be prepared to make future with company in South America. Transportation to South America paid. Application by letter. Location, Chile. V-1882.

YOUNG COLLEGE GRADUATE to learn sales work. Electrical or mechanical graduate preferred. Will need to spend 1½ years in office learning company's business and sales work before undertaking responsible sales work. Application in person. Location, New York. V-1883.

ENGINEER familiar with automatic magnetic control of motors and who also understands something about the theory and application of electro-magnets for this purpose. Large steel mill using a specially designed machine for automatically laying out and punching holes in structural steel. Machine has been developed to a high state of perfection but there are little kinks that occur now and then which have to be

ironed out, and which therefore requires a man who, besides electrical knowledge possesses some initiative to solve these problems. Application by letter or person. Location not stated. V-1886.

INSTRUCTOR in electrical engineering beginning Sept. 20th. Must be graduate in electrical engineering and be able to teach fundamentals of electrical engineering in class and laboratory. One or two years practical experience necessary. Application by letter giving full particulars and references. Location, Middle West. V-1893.

ENGINEER having some or all of following qualifications. Experience in design of industrial electric furnaces. Experience in application of industrial electric furnaces. Such general metallurgical and industrial experience as would form good groundwork and enable engineer to apply industrial electric furnaces after brief special training. Application by letter. Salary not stated. Location, Pa. V-1894.

DRAFTSMEN (2 or 3) experienced in steam-electric power station work. Application by letter. Location Illinois. V-1899.

RADIO & ELECTRICAL ENGINEER wanted to take charge of sales and development work of radio and electric wiring device specialties. Splendid opportunity for ambitious young man to make his own future. Application by letter. Salary not stated. Location, New York City. V-1900.

ENGINEER (graduate) versed in mathematics; heat balance, etc. of industrial drying as applied to chemicals, textiles and leather. Will be employed on calculations, tests and sales. Also men to train for salesmen. Application by letter. V-1901.

TECHNICAL MECHANICAL ENGINEER who has had four or five years power engineering experience, testing of power plant apparatus and consumption of steam, air, water, electricity, etc. of industrial plant equipment. An engineer of good potential and of considerable tact and diplomacy wherewith he can, in the prosecution of his work, enlist the cooperation of plant operatives over whom he would have no direct authority. Application by letter. Salary not stated. Location, Delaware. V-1906.

JUNIOR POWER ENGINEER just out of college, or who has had one or two years practical experience. Application by letter giving age, education and experience. Salary not stated. Location, Delaware. V-1907.

CHIEF DRAFTSMEN for company manufacturing air compressors. Twelve inch stroke and shorter; steam and power pumps, twelve inch stroke and shorter. Need men who can keep line up-to-date. Application by letter. Location, Illinois. V-1910.

ENGINEER for Editorial Dept. particularly for outside work. Must be familiar with power plant machinery and practise, but should be a man who has sales engineer characteristics, that is, a good personality, capable of meeting most important men in field and securing good will and cooperation, and with a broad view as to future progress of power plants. Age about 35. Experience in editing not essential. Salary not stated. Application by letter. Location, Illinois. V-1921.

INSTRUCTOR in mechanical drawing, descriptive geometry and mechanism. Prefer some one with experience as a teacher and with some practical experience. Appointment would be for three years beginning Sept. 1922. Application by letter. Location, Constantinople. V-1928.

INSTRUCTOR in mathematics including descriptive geometry and surveying. Appointment for three years beginning Sept. 1922. Recent graduate of some good engineering school preferred. Appointment by letter. Location, Syria. V-1929.

ELECTRICAL ENGINEER graduate. 5-10 years experience on switchboard and wiring layout. Location, Alabama. Application in person. V-1930.

ELECTRICIAN practical and capable of laying out work. Must be willing and able to do house wiring etc. himself when necessary. Excellent opportunity. Application by letter. Salary not stated. Location, Yonkers, N. Y. V-1931.

INDUSTRIAL ENGINEER. Practical man to go over affairs and help devise a system that would be more practical and efficient. Company engaged in wholesaling of plumbing and steam fitting, and mill supplies. Application by letter. Salary not stated. Location, New Jersey. V-1938.

SUPERINTENDENT for plant manufacturing lead covered cable. Salary not stated. Application by letter. Location, Vicinity N. Y. V-1943.

MANUFACTURING COMPANY of diversified products offers definite opportunities for several recent graduates of technical universities to avail themselves of training in operating departments for ultimate positions with engineering and sales staffs. State qualifications in complete detail and give reference to faculty members. Salary not stated. Application by letter. Headquarters, Wisconsin. V-1953.

SALES ENGINEER experienced in handling overhead cranes, trench excavators and gasoline shovels. Should be experienced on gas engines. Single men not over 30 years old. Application by letter. Location, New York City. V-1955.

SALES ENGINEER with executive ability. Salary not stated. Application by letter. Location, New Jersey. V-1957.

ENGINEERS specialized in manufacture and installation of electrical panel boards and steel cabinets. Competent men to design and supervise the manufacturing of distribution centers are especially desired. Salary not stated. Application by letter. Headquarters, Pa. V-1962.

ENGINEER. Age 28-35 in Contract and Bond Department. Must have at least 5 years active experience in construction work; good personality, and ability to talk convincingly. Must travel, so prefer single man. Not a high salaried position at start, but opportunity for advancement is good. Application by letter giving complete data including salary received in each position and references. Interview can be arranged in any large city. Headquarters, Conn. V-1963.

ELECTRICAL DRAFTSMAN. Need not be college graduate but rather one who has had drafting and some construction experience. Should have had sufficient practical experience to familiarize him with apparatus used in power plant and substation construction and sufficient experience to know what is required to make a finished drawing. Salary not stated. Application by letter. Location, Pa. V-1964.

GRADUATE ENGINEER age not over 35 to act as instructor in descriptive geometry. Should have not less than 3 years experience as mechanical draftsman with some reputable manufacturing concern. Application by letter. Location, Georgia. V-1975.

CHIEF OPERATING ENGINEER in charge of turbines and engines in Paper Mill. Must be fully qualified. Application by letter. Salary not stated. Location, Ohio. V-1980.

ESTIMATOR. Designer preferably with experience in consulting engineers office on power generating equipment. Must be capable of making plant survey to determine power requirements for extensive new installations. Application by letter. Salary not stated. Location, Ohio V-1981.

GRADUATE ELECTRICAL ENGINEER for Commercial Dept. Good personality and experienced in selling electric power to industrial concerns. Application by letter. Location, New York State. V-1985.

RECENT GRADUATE CHEMICAL ENGINEER to enter industrial organization. Man looking for an opportunity and willing to start in a modest capacity and at a nominal wage. Application by letter giving detailed outline of training and experience accompanied by a recent photograph. Application by letter. Salary not stated. Location, Pa. V-1987.

HIGH-GRADE SALES REPRESENTATIVES (2) men with mechanical knowledge, to act as special sales representatives in assisting branch managers analyze and promote sale of motor trucks to (1) oil and gasoline industries (2) packing, wholesale grocery and food products. Must have thorough knowledge of, and wide acquaintance with executives of one of the above industries, and travel extensively. Application by letter giving personal characteristics, business experience in detail, salary expected and date available. Headquarters, Ohio. Salary not stated. V-1993.

METALLURGISTS on steel castings for bottle molds in electric foundry. Salary not stated. Application by letter. Location, Ohio. V-1998.

YOUNG ENGINEER with some experience in production department of hosiery manufacturing concern. Twenty-five or thirty years of age. Should understand the manufacture of hosiery. Application by letter. Salary not stated. Location, New York City. V-2014.

YOUNG ELECTRICAL ENGINEER with practical experience along construction and designing lines for position as Assistant to Electrical Engineer in connection with development and construction on high tension system. Experience in Transmission and Power Plant work essential. Good future. Application by letter enclosing recent photograph. Salary not stated. Location, Pa. V-2016.

ELECTRICAL ENGINEER with experience on installation and operation of small electric light plant. Application in person. Location, Hayti. V-2017.

MECHANICAL ENGINEERS (2) for inspection of industrial plants in Middle West. These men are for indemnity insurance company. An operating steam engineer preferred who has a good appearance as he will have to meet officials of firms insured. 5-6 years experience. Location, travelling Middle West. V-2019.

GENERAL MANAGER thoroughly familiar with the design, manufacture and sale of fractional horse power motors. Must be engaged in the business at present time or have been so engaged at a recent date. Application by letter. Salary not stated. Location, Michigan. V-2023.

SALESMAN or REPRESENTATIVE for simplified course in bookkeeping and accounting. Endorsed by leading firms. Application in person. Salary not stated. Headquarters, New York City. V-2024.

TEST ENGINEER for Power Station. Mechanical Engineer with one or two years power house experience with oil fuel, and competent in analysis of boiler water and flue gases. Application by letter. Location, Chile. V-2029. (3 yr. contract).

MECHANICAL ENGINEER, recent graduate familiar with water, air and gas measurements, flow meters, pressures and temperatures. Three year contract. Application by letter. Location, Chile. V-2030.

MECHANICAL ENGINEERS. (2). Experienced on design and construction work for power houses, refrigerating plants. Man 35-45 years of age. Application in person, New York City, Location, Washington, D. C. V-2032.

ELECTRICAL ENGINEER, design and layout equipment for power house. Man 30-45 years of age. Application in person, New York City, Location, Washington, D. C. V-2033.

ELECTRICAL DRAFTSMEN (2) experienced on steam power station, substations and transmission lines. Location, New York City. V-2042.

DRAFTSMEN (2) on hydroelectric power plants. Civil engineer graduate with experience on heavy reinforced concrete. Application by letter. Salary $225. Location, New York City, V-2041.

DRAFTSMAN experienced on fuel oil piping layout for furnace work. Application by letter. Salary not stated. Location, New York City. V-2053.

ELECTRICAL ENGINEER, recent graduate for testing, estimating and general layout work in connection with large underground distribution system. Application by letter. Salary not stated. Location, Nebraska. V-2055.

CHEMIST OR CHEMICAL ENGINEER with Ph. D., about 30 years old, experienced in teaching or practical work along analytical lines to act as Instructor at University. Application by letter. Location, Washington, D. C. V-2056.

ASSOCIATE PROFESSORSHIP in Electrical Engineering. Application by letter. Location, Texas. V-2064.

ELECTRICAL ENGINEER capable of directing the operation of transmission lines and stations over a territory 75 miles in extent. There will be three assistants to handle the shift work. Application by letter. Location, N. Y. State. V-2066.

ELECTRICAL ENGINEER experienced on the design of hydroelectric equipment. Must bring experience record. Application in person by appointment. Location, New York City. V-2068.

MECHANICAL ENGINEER experienced on design and test along power plant and steam apparatus lines. Operation experience desirable. Application by letter. Location, New York City V-2069.

ELECTRICAL ENGINEER with at least two years' practical experience, for work on design and construction of electric locomotives and car equipments. Application by letter giving age, education, experience and three references. Salary not stated. Location, Pa. V-2076.

PRODUCTION & FACTORY ENGINEER with motor cycle experience. Must also be familiar with automotive industry. Application by letter stating age, education and experience. Only men with this experience considered. Location, Mass. V-2081.

DRAFTSMAN to design electrical fittings of various kinds. Will develop modifications of existing fittings, complete line of sizes from one size, the working out of ideas suggested and supervise the making of suitable models. Application by letter. Location, Pa. V-2095.

ELECTRICAL ENGINEER with some practical experience to act as instructor. Must be graduate of first class technical school. Application by letter. Location, Maine. V-2096.

HIGH GRADE SALES EXECUTIVE with broad knowledge of industrial field to carry on an educational industrial campaign among manufacturers; complete details required. Application by letter. Headquarters, New York City. V-2097.

DESIGNER experienced on fuel oil burning equipment. To act as adviser on commercial and engineering development work. Application by letter. Salary not stated. Location, New York City. V-2098.

SALESMAN for power house and transmission equipment. Preferably man under 35 years of age. Application by letter giving education and experience. Salary not stated. Headquarters, Pa. V-2102.

ECONOMY ENGINEER for power plant for steel mill. Must be able to go through entire plant as well as power plant and suggest economies in operation. Application by letter only giving age, education and experience. Location not stated. V-2103.

ARCHITECTURAL DESIGNER on Round House. Man familiar with piping layouts for plumbing and toilets and general reinforced concrete. Application in person. Location, New York City. V-2104.

1922 GRADUATE for planning division to schedule jobs. Application in person. Location, New York City. V-2105.

ELECTRICAL ENGINEER with experience on electrification of Textile mills. Man about 28-30 years of age for resident engineer on job to supervise installation. Application by letter. Salary not stated. Location, New York and vicinity. V-2106.

DISTRICT SALES MANAGERS for company manufacturing automatic solenoid flashers. Application by letter. Salary not stated. Location, New York City. V-2108.

SALES ENGINEERS, three of these men are to possess the qualifications requisite to apply gas fired steam boilers in industries and also for house heating. One for application of gas fired appliances for heat treatment of metals and one to possess qualifications for application of gas to gas-burning equipment to large bake ovens. Application by letter. Location, New York. V-2110.

ELECTRICAL ENGINEERS with G. E. or Westinghouse test floor experience supplemented by road work and office report training to act as Inspectors for Insurance company. Must know insulation, windings and electrical equipment. Application by letter. Location, various. V-2119.

ESTIMATOR on pipe coverings and asbestos products. Application by letter. Location, New York City. V-2126.

YOUNG ENGINEER to order out material on contract, prepare orders for factory, follow up progress of delivery, etc. Must be able to run typewriter and must know asbestos products. Application by letter. Location, New York City. V-2127.

ENGINEER for Commercial Engineering work with railway equipment customers. Technical men and preferably one who has had some experience in operation of electric railways or electrical railroads. Work will consist of investigating customers' maintenance problems and be able to design and recommend renewal parts for motors and control. Application by letter. Salary not stated. Location, Pa. V-2135.

ENGINEER interested in design and construction of rotating electrical apparatus to take up designing with manufacturing company. Experience highly desirable. Technical training essential. Application by letter stating training and experience. Salary dependent upon ability and experience. Location, Pa. V-2136.

EXPERT BOILERMAKER FOREMAN thoroughly experienced in all practical phases of standard boiler construction, familiar with A. S. M. E. boiler code layout of templates for shell plates, heads, crown sheets, etc. Must thoroughly understand process of bending, flanging, scarfing, etc. and be able to make quick survey for repairs and reasonable estimate on time to do the work. Application by letter. Salary not stated. Location, Ohio. V-2138.

SALESMAN broadly experienced on lighting fixtures. Application by letter. Location, Jacksonville, Fla. V-2139.

MARINE ELECTRICAL DRAFTSMAN, first class. Application by letter Salary not stated. Location, Virginia. V-2148.

ENGINEER with substation, switchboard, transmission line experience, etc. to act as Squad Boss. Location, New York City. V-2150.

ENGINEER throughly versed in power plant lubrication to take charge of technical work in Italy. Must be native born Italian with American training. Man 30-40 years old, having had power plant experience. Location, Italy. V-2167.

ENGINEERS to become executives for large chain of stores. First qualification, sales work. Commission and bonus. Location not stated. Application in person. V-2156.

INSPECTORS on automatic telephones, switch boards, etc. Application by letter. Location, N. Y. C. V-2158.

YOUNG ELECTRICAL ENGINEER capable of handling service correspondence, making tests and compiling data. Application by letter stating experience and salary expected. Location, Wisconsin. V-2171.

INDUSTRIAL GAS APPLIANCE SALESMAN. One who is a business getter, and can bring in results. Contemplate opening an industrial department and want first class man who would be willing to create and make this department what it should be. Application by letter. Salary not stated. Location, Virginia. V-2173.

ENGINEER experienced in estimating water tube boilers and heavy plate work. Excellent opportunity for advancement to engineering department. Application by letter. Salary not stated. Location, Missouri. V-2174.

FOREMAN—Dry Press Shop. At present department employs 40-50 persons. Must have had experience in dry-pressing of porcelain. Position eventually leads to superintendency of plant. Age 30-35, technical education not essential, but experience is. Application by letter. Salary depending on experience of applicant. Location, Ill. V-2179.

GRADUATE ELECTRICAL ENGINEERS (2) or DESIGNING DRAFTSMEN, with two to five years experience on electrical apparatus, such as substations and switchboard designing, public utilities organization. Application by letter. Location, Pa. V-2193.

DESIGNING ENGINEERS (6) (graduate Electrical engineers required) for substation and switchboard designing, public utilities central station work. Application by letter. Location, Pa. V-2194.

DESIGNING DRAFTSMAN, graduate electrical engineer. Must be good letterer. Send sample of drawing with application, central station. Location, Pa. V-2195.

ASSOCIATE EDITOR for engineering journal. General qualifications: Age 28-35; engineering education preferably mechanical; shop experience preferably as an executive; some editorial experience or its equivalent; personality; the ability to mix. Application by letter. Salary not stated. Location New York City. V-2117.

GENERAL MANAGER thoroughly familiar with the design, manufacture and sale of fractional horse power motors. Must be engaged in the business at present time or have been so engaged at a recent date. Application by letter. Salary not stated. Location, Michigan. V-2023.

FOREMAN of die and machine shop with knowledge of special porcelain dies. Shop employs 12 men. Application by letter. Salary $50. Location mid-west. V-2204.

MEN AVAILABLE

ELECTRICAL ENGINEER, technical graduate; Assoc. A. I. E. E. Age 28. Six years experience in testing laboratory radio, chief engineer of marine installation and maintenance; remote control, machine tool application, estimating and construction work. Desires permanent position with well established company, planning, estimating and following up progress of jobs. Location preferred Newark or New York City; available one month. E-3476.

SALES MANAGER, graduate Electrical and Mechanical Engineer University California fourteen years experience desires connection sales executive property or company requiring commercial expansion and rejuvenation and where permanent future and advancement will depend upon new revenues produced. At present employed. Communications with high types of organizations solicited. E-3477.

GENERAL MANAGER—Over twenty-years experience in Construction, Operation, Management of Public Utilities. General Manager large Railway, Gas and Power Company prior to the war. Know the business from the coal pile to the public. Successful executive, energetic and tactful. Age 47, married, American, several years experience abroad, speak Spanish. Available now. E-3478.

ELECTRICAL ENGINEER or SUPERINTENDENT-PRODUCTION or EFFICIENCY ENGINEER desires connection with Engineer-

ing Constructing manufacturing or Public Utility. Best of references and no reasonable offer refused. E-3479.

ELECTRICAL ENGINEER who has specialized in Illuminating Engineering for the last fifteen years desires to deliver a course of lectures on this and allied subjects. E-3480.

ASSISTANT TO SALES MANAGER, electrical engineering graduate, age 28, with 1 year shop, 1 year office, 1 year sales representatives and 1 year teaching experience desires position in sales office of manufacturer. E-3481.

ELECTRICAL & MECHANICAL ENGINEER. Age 28, married, family, permanently located in New York. Experienced in handling men, non-graduate, of two universities, 1½ years engineering and correspondence work with well known manufacturer of Elect. Control equipment. 1½ years as special Eng. developing means and methods of marine salvage. 6½ years active naval service holding all ratings from Landsman for Elect. to and including Lieut. Jr. Eng. Now employed. E-3482.

GRADUATE ELECTRICAL ENGINEER, Associate A. I. E. E., G. E. Test, with exceptional practical experience in the application and operation of electrical apparatus in the Coal Mining Industry. Also experienced in Power Plant and Substation operation. Desires position with coal or Public Utility Company, preferably in central Pa. E-3483.

YOUNG ELECTRICAL ENGINEERING GRADUATE, having had eighteen months experience on General Electric Co. test, an Associate of A. I. E. E. Desires a position in electrical engineering work in which there is opportunity for advancement. E-3484.

ELECTRICAL SUPERVISOR or ASSISTANT ELECTRICAL SUPERINTENDENT INDUSTRIAL PLANT; technical graduate 1917, married—28, familiar with electrical-mechanical construction and operation, good executive. Schenectady tests, experienced in dielectric phenomena and electrolysis of structures. Available on short notice. Minimum initial salary $2100. E-3485.

TECHNICAL GRADUATE, B. Sc. in Electrical Engineering, also two years of Law—age 23, single, Enrolled Student A. I. E. E., good character, have some experience with Western Electric in switchboard installation and testing. Experience before salary. Desires position with public utility company or electrical manufacturing concern. E-3486.

ELECTRICAL, STEAM & COMBUSTION ENGINEER desires position as Superintendent or Chief of Electric Light & Power Plant, or with Manufacturing Company in same capacity. 20 years experience licensed. At present employed, good reason for making a change. Member A. I. E. E. Will consider other position if with a good company with chances for advancement. E-3487.

ENGINEER—Assoc. A. I. E. E. Available at once. University man, married, and 33 years of age. With 11 years engineering, executive, and sales experience, including 19 months G. E. test course and 14 months as inspector of British Army plants in France and Flanders. Prefers to take agency for manufacturers, in Canada or office executive or sales position. E-3488.

ELECTRICAL ENGINEER; B. Sc. in E. E., Rutgers, 1922. Enrolled Student A. I. E. E. Age 25. No practical experience. Desires position with traction or manufacturing company. Location, unimportant. E-3489.

GRADUATE ELECTRICAL ENGINEER, age 31, married, two children, past two years engineering department well known consulting engineering firm, experienced in design and operation lighting and power layouts for powerhouse, industrial plants, office buildings, etc., desires change in position in similar work, due to uncertainty of location in present connection. Other details gladly furnished. E-3490.

PUMP ENGINEER—Electrical Engineer, A. I. F. E.—Age 33—Married—Competent to give estimates and recommendations for all classes of pump installations. Four years specializing in pump field—Previous experience confined to power plant construction and maintenance—Now employed as pump engineer and desires connection in New York City or immediate vicinity. E-3491.

FERTILIZER AND CHEMICAL PLANT ENGINEER. Twelve years with one company in responsible charge of Construction and Operation. M. I. T. Graduate. E-3492.

DRAFTSMAN, electrical, technical education twelve years experience in power and substation design and construction, also estimating, desires position as field engineer or construction superintendent. E-3493.

MECHANICAL AND POWER ENGINEER, technical graduate, B. S. and M. E., eight years broad experience, machine shop, metallurgy, sugar engineering, industrial and power plant, practise, operation, design, layout, calculations, heat-balance, utilization and distribution of steam, water, coal, power, etc., investigation, research, reports. Executive and business ability. E-3494.

WORKS ENGINEER TECHNICAL GRADUATE, Assoc. A. I. E. E., experienced in installation and operation of power and production equipment. Three years plant engineer of metal working plant with 1200 hands. Four years on factory and power plant layout and design of special machinery and tools. Practical machinist. Position desired where thorough knowledge of shop and power plant practise is required. Salary $300 per month. E-3495.

RADIO ENGINEER, Assoc. A. I. E. E. and I. R. E., desires permanent connection with radio manufacturer, preferably in the East. Ten years radio experience. Two years college E. E., two years Chief Electrician (Radio) Navy. Recently engaged in developing, designing and estimating of radio frequency amplifiers and complete receivers. First grade commercial operator's license. Married. E-3496.

SMALL MOTOR SPECIALIST. Engineering School training, plus eight years of "practical" experience, on all types, specializing on small single-phase lines. Good knowledge of fan production. Seek supervisory or similar work on test, assembly, etc. with mfg. corporation. Associate A. I. E. E. Age 28, married. A-1 references. Small salary to start. E-3497.

PROFESSOR OF ELECTRICAL ENGINEERING. Member A. I. E. E., A. B. and M. E. E. from Harvard. Age 33. Present salary $4500. Thirteen years teaching experience, 9 in present position. Desires to change to another teaching position or into either the consulting engineering or telephone field. Articles written for *London Electrician*, *Electrical World*, *Power*, *S. P. E. E. Bulletin*, etc. Translation ability in French, German and Italian. E-3498.

GENERAL MANAGER, age 37, married, 15 years experience, hydroelectric public utilities. Construction, operation, commercial. Successful executive. Energetic. Familiar with necessity of molding public opinion favorably to power corporations, desires to locate with growing power company, United States, Canada, or South America. Available September 1st. Minimum salary $5000.00. ($6,000). E-3499.

CONTROLLER ENGINEER with more than 10 years experience on drum controllers, dimmers and automatic control of various kinds will consider offer. Have had considerable executive experience. Licensed professional engineer New York State and member of A. I. E. E. Salary $3600 to $4000. E-3500.

ELECTRICAL and MECHANICAL ENGINEER, technical graduate, seven years experience along broad lines covering design, purchasing and production in connection with manufacture of steam power plant equipment, design and construction of power plants, industrial plants, sulphuric acid plants, and mining; investigations and estimates. Age 32, Assoc. A. I. E. E. E-3501.

ELECTRICIAN, age 21, 5 years experience in electrical construction and maintenance of electrical machinery. Completed a four year course in electrical engineering at Lewis Institute. Desires a position as a beginner in electrical engineering. E-3502.

ELECTRICAL ENGINEER—M. I. T. graduate, one year teaching experience, two years oil field construction work, one year experimental and test work on mechanical apparatus. Outdoor construction work preferred but not essential. Location immaterial. Available at once. E-3503.

YOUNG ELECTRICAL ENGINEER, B.S. in E.E., graduate La Salle Accounting course, married, G. E. switchboard and other testing experience, several years checking the cost of installation of electric railway equipment, desires position with company where the opportunity for advancement is good. Present salary $2000. Location, Northeastern States. E-3504.

ELECTRICAL OPERATING SUPERINTENDENT — American. Practical, energetic man. 30 years of age—married. 3 years university in E.E. 8 years practical experience operating light and power and water utilities, member A. I. E. E. location Middle West, excellent references. Available immediately. E-3505.

ELECTRICAL ENGINEERING GRADUATE with one year's operating experience on a hydroelectric station, and 18 months G. E. test, desires employment with a power company or consulting engineering firm on hydroelectric work. E-3506.

ELECTRICAL ENGINEER. Experienced in layout, installation and maintenance of electrical equipments and plants; desires position with consulting engineer, or as electrical superintendent in charge of factory or as superintendent of construction. E-3507.

RECENT ELECTRICAL ENGINEERING GRADUATE, age 22, desires position with moderate sized manufacturing concern in New York City. Opportunity for future is first consideration. E-3508.

YOUNG MAN—age 20, seeks position in electrical industry with opportunity of advancement. Has had considerable experience in armature winding, trouble shooting and wiring. Graduate from evening technical school. Enrolled Student A. I. E. E. Vicinity Toronto. E-3509.

RECENT E.E. GRADUATE, B.S. degree, desires engineering position with industrial or public service company, offering a future. American, single, age 24, good health. Two years commercial radio experience. E-3510.

ENGINEER-EXECUTIVE, B.S. & E. E. Member A. I. E. E. Experience covers research work, design and field work on electric control, technique of duplicate parts manufacture in several fields, superintendency of two plants. Patentee numerous devices now in manufacture. Desires change to position of responsibility. E-3511.

YOUNG ELECTRICIAN, age 27, married, wants position with chance for advancement; high school education, served four years electrical construction and three at repair; graduate technical trade course in armature winding and motor repair. Two years' service, during the war, as electrician in U. S. Army. Location, anywhere. E-3512.

TECHNICAL GRADUATE, age 23, desires position with electric and manufacturing or engineering concern where a good future will be assured. Now employed as electrical sales correspondent and formerly with public utility on meter testing. Possesses sound business training. Ambitious, capable and hard worker. Available on two weeks notice. E-3513.

YOUNG MAN—Age 21, will receive B.S. degree in electrical engineering from Cooper Union Night School in June. Enrolled Student A. I. E. E. Three years experience as draftsman and assistant to engineer of large plant. Experience in designing, installing and repairing radio receiving sets. E-3514.

ELECTRICAL ENGINEER, technical executive, good personality. Six years Public Utility operating and Engineering; four years in charge of Testing Dept. of Electrical Manufacturer; two years consulting engineering designing and supervising work. Best references. Salary dependent on future. E-3515.

FACTORY ENGINEER or SUPERINTENDENT, Grauate Electrical Engineer, Age 38, Married; sixteen years experience in manufacture of small electro-mechanical devices, broad experience including electrical measuring instruments, switchboards, radio, lighting and appliances. Desires charge of development and quantity production of similar product in a growing business. E-3516.

TELEPHONE ENGINEER OR MANAGER. Sixteen years in telephone manufacturing and operating. Thoroughly familiar with latest apparatus and methods. Work has included design, installation, maintenance, traffic and managing. Looking for large job. E-3517.

GRADUATE ELECTRICAL ENGINEER. Age 27, single. Four years experience on General Electric test and with operating company, also radio experience. Assoc. A. I. E. E. and Assoc. I. R. E. New England or Middle Atlantic States preferred. E-3518.

RECENT TECHNICAL GRADUATE (electrical) age 26, single, desires position with public utility company, but will consider any offer in any other capacity or in any other line. Has 5 years experience as electrician. Has initiative, ability. Location, Central or Southern States. E-3519.

TECHNICAL GRADUATE—age 23 with 7 years practical experience, consisting of experimental and research work, central station and manufacturing, with the past two years inspector and tester of automatic electric apparatus, desires position offering permanent location and future. Position offering location in medium sized city preferred. E-3520.

DESIGNING and PRODUCTION ENGINEER on small motors, both D. C. and A. C. Technical graduate, two years' test floor experience, three years in designing, development and production work on small motors. Would like to take charge of small motor department or a position as production engineer or designer for a motor manufacturer. Age 29, married. E-3521.

ELECTRICAL ENGINEER, graduate 1922, with 6 years experience including house wiring, armature winding, substation operating and building engineer. One year experience in the U. S. Naval air service as Machinist's Mate and Radio electrician. Age 29, married. Desires employment with reliable radio concern. E-3522.

ELECTRICAL ENGINEER, 36 years old, with 17 years experience in design, construction and operation of power and substations, industrial plants, underground and overhead feeder distribution and high tension transmission systems electrolysis investigations, specifications, maintenance of electrical and mechanical apparatus, reports on operating characteristics, desires an executive position. Member A. I. E. E. E-3523

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED AUGUST 8, 1922

ADAMS, NORMAN I., JR., Sloane Physics Laboratory, Yale University, New Haven, Conn.; res., 22 Eliot Road, Lexington, Mass.

AHRENS, ORTGIES, JR., Electrical Tester, Western Electric Company, 104 Broad St., New York, N. Y.; res., 221 Clinton Ave., West Hoboken, N. J.

ANDERSON, FRANK HARRY, Dynamo Operator, New York Edison Company, 123 E. 83rd St., New York, N. Y.; res., 1109 Park Ave., Hoboken, N. J.

ASH, PHILIP PAUL, Signal Maintainer, Louisville & Nashville Railroad Company, Henderson, Ky.

ASLANIDES, D. J., C. P. Rizopoulos & D. G. Araboglou, 46 Galata Quay, Constantinople, Turkey.

BASSETT, WALTER GUY, Assistant Operator, United Light & Power Co., Hellgate Station, E. River & 134th St.; res., 4010 Hill Ave., New York, N. Y.

BEMIS, PAUL DANA, Junior Electrical Engineer, G. F. Hardy, 309 Broadway; res., 605 W. 138th St., New York, N. Y.

BIRD, JEWETT DOUGLAS, Electrical Designer, Chase Company, Inc.; res., 39 Ridgefield Ave., Waterbury, Conn.

BLOEM, CORNELIUS J. C. M., 630 Belvedere Ave, Plainfield, N. J.

BLUMEL, ANTHONY, Electrician, 14325 Euclid Ave.; res., 16216 Park Grove Ave., Cleveland, Ohio.

BRADY, EDWARD A., Service Dept., Westinghouse Electric & Mfg. Company; res., 3122 G St., Philadelphia, Pa.

BRAIN, VIVIAN JAMES FOXTON, Student Engineer, International General Electric Company, Inc.; 24 Wendell Ave., Schenectady, N. Y.

BROWNFIELD, ERNEST S., Chief Electrician, St. Paul & Tacoma Lumber Company, Tacoma, Wash.

BUNNETTA, GEORGE ALLEN, Assistant Managing Engineer, Jost's Engineering Co., Ltd., Apollo St., Bombay, India.

BURD, HARRY G., General Sales Manager, National Conduit & Cable Company, 17 E. 42nd Street, New York, N. Y.

BURKHEAD, CALVIN H., Captain, Signal Corps, U. S. Army, 3113 Arcade Bldg., Seattle, Wash.

*CASTAGNARO, DOMINICK, 967 3rd Ave., Brooklyn, N. Y.

CHACE, MYRON D., Telephone Engineer, New England Tel. & Tel. Co., 50 Oliver St., Boston, Mass.

COLEBERT, REED JOSEPH, Sales Manager, Pure Carbon Company, Wellsville, N. Y.

COMBES, FRANK ROY, Assistant, Switchgear Development Dept., General Electric Company, Witton; res., 374 Slade Road, Erdington, Birmingham, England.

CONNETTE, THOMAS WRENNE, General Manager, Lockport Light, Heat & Power Company, 115 Main St., Lockport, N. Y.

CRISP, MILES H. T., Burma Corporation, Ltd., Namtu, Northern Shau State, Burma, India.

CRONIN, VINCENT PAUL, Assistant Electrical Engineer, Rawson Electrical Instrument Co., 4 Norfolk St., Cambridge, Mass.

CROWLEY, CORNELIUS, Assistant Engineer, Dept. of Public Works; res., Free State, Newmarket, Brisbane, Queensland, Aus.

DAVISON, ALEXANDER, Electrician, C. M. S. Company, Trail, B. C.

DIGBY, JOHN CHARLES, City Electrician, Corporation Electric Light Plant, City Hall, New Westminster, B. C.

DOUGHERTY, SAMUEL McCARRELL, Service Engineer, Westinghouse Electric & Mfg. Co.; res., 4321 Berkeley Ave., Chicago, Ill.

EDDY, WILTON NATHANIEL, General Engineering Laboratory, General Electric Company; res., 326 Glenwood Blvd., Schenectady, N. Y.

EVERETT, RICHARD E., Electrical Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wisconsin.

FARRUGIA, JOSEPH M., Telephone Tester, Western Electric Company, 151 5th Ave.; res., 324 W. 18th St., New York, N. Y.

FERGUSON, FRANCIS GORHAM, Turbine Engineering Dept., General Electric Co., W. Lynn; res., 87 Endicott St., Peabody, Mass.

FORBATH, JOHN, Telephone System Dept., Western Electric Company, 463 West St.; res., 2390 Creston Ave., New York, N. Y.

FOWLER, THOMAS CLARK, General Superintendent, Construction Dept. & Repair Shop, The Salzer Electric Company, 420 High Ave., Cleveland, Ohio.

*FURUI, SHUNGO, Student, Dept. of Electrical Engineering, Stanford University, Stanford University, Calif.

GALE, LIONEL GEORGE, Electrical Draftsman, Richard D. Kimball Company, 6 Beacon St., Boston; res., 52 Adams St., Winter Hill, Mass.

GODDARD, CHARLES WILLIAM, Chief Electrician, Canadian Brill Company, Ltd., Preston, Ont., Canada.

GOLDEN, MARCEL M., Electrical Engineer, Constructions Electriques de France, 19, Rue Louis-le-Grand, Paris, France.

GOMES, FRANCISCO, Electrical Engineer, Companhia Brazileira de Energia Electrica, Rue da Conceicao No. 29, Nictheroy, E. do Rio de Janeiro, Brazil, S. A.

GREER, ROBERT TYSON, Asst. to Superintendent of Steam Stations, Consolidated Gas, Electric Light & Power Company; res., 2728 Maryland Ave., Baltimore, Md.

*GUNN, ROSS, Instructor in Engineering Physics, University of Michigan, Ann Arbor, Mich; res., 369 W. Lorain St., Oberlin, Ohio.

HAGER, WAYNE, Superintendent, Electrical Dept., Galesburg Railway, Light & Power Company, 7 E. Main St., Galesburg, Ill.

HANSEN, AUG. E., Electrical Sales Dept., Fairbanks, Morse & Company, 220 E. 5th St., St. Paul, Minn.

HEATH, CHARLES ELMER, Asst. to Superintendent, Transmission Dept., Southern California Edison Company; res., 2016 Fanning St., Los Angeles, Cal.

HILBERT, EUGENE ROBERT, Safety Engineer & Chief Electrician, Standard Textile Products Company, Athenia, N. J.

HOLBEACH, CONSTANTINE HUGH, Electrical Engineer & X-Ray Specialist, British Thomson-Houston Co., Ltd., 77 Upper Thames St., London, E C. 4, Eng.

HOPKINS, LAWRENCE L., Technical Librarian, General Electrical Company; res., 2 Van Velsen St., Schenectady, N. Y.

JACOB, WILLIAM FREDERICK, Engineering Librarian, General Electric Company; res., 17 Lakewood Ave., Schenectady, N. Y.

JAMES, HAROLD BELDEN, Telephone Engineer, American Tel. & Tel. Company, 225 E. 4th St., Cincinnati, Ohio.

KINKAID, CHARLES P., General Superintendent, Washington Coast Utilities, 620 New York Block, Seattle, Wash.

KRIGEL, JOSEPH ANTHONY, Instructor, U. S. Naval Radio School, Great Lakes, Ill.

LANDGREN, ALBERT VINCENT, Junior Engineer, Nebraska Power Company; res., 2437 S. 24th St., Omaha, Neb.

LASKEY, HARRY S., Superintendent & Estimator, The Scannell Electric, 709 Adams St.; res., 2033 Carrollton Ave., Toledo, Ohio.

LINDBLAD, WILLIAM NATHANE, Assistant Chief, Bureau of Tests & Inspections, Pacific Gas & Electric Company, 2101 Mariposa St., San Francisco, Cal.

MAJOR, OSCAR SELLON, Asst. to Signal Engineer, Kansas City Southern Railway; res., 3121 Chestnut St., Kansas City, Mo.

*MANNING, LEON J., Assistant Electrical Engineer, West Indies Sugar Finance Corp., Central Tanamo, Cayo Mambi, Oriente, Cuba.

MATHER, ROBERT HARRISON, Consulting Engineer, Buck and Sheldon, Inc., 60 Prospect St., Hartford; res., 51 Elm St., Windsor Locks, Conn.

McENTEE, FRANK JAMES, Chief Electrician, Union Pacific Coal Company, Winton; res., Megeath, Wyoming.

MEEK, CECIL P., Carrier Telegraph Repeater Attendant, American Tel. & Tel. Company, 4701 Kedzie Ave., res., 4356 Lake Park Ave., Chicago, Ill.

MENDENHALL, IVAN SWAIN, Research Engineer, Detroit Edison Company, Detroit, Mich.

MEYEREND, FRANK MANLEY, Commercial Engineer, Bronx District, New York Edison Company, 555 Tremont Ave., New York, N. Y.

MIGLIORI, ERMINIO, 102 Ring St., Providence, R. I.

MILLER, HOWARD C., Station Maintenance Engineer, Utah Power & Light Company, Oneida Station, Preston, Idaho.

MORCH, PHILIP C., Asst. Inspector, Electrical Material, Navy Yard, New York; res., 93 Chestnut St., Brooklyn, N. Y.

MOWRY, ALLEN H., Assistant Manager, Electrical Sales Dept., American Steel & Wire Company, 30 Church St., New York, N. Y.

MURDOCK, EDWARD S., Superintendent, Electrical Dept., Generating Station, Union Electric Light & Power Company, Main & Ashley Sts., St. Louis, Mo.

NAYLOR, JOSEPH EDWARD, Telephone Engineer, Western Electric Company, Hawthorne Station, Chicago; res., 106 5th St., Aurora, Ill.

NELSON, HAROLD F., Sales Engineer, Westinghouse Electric & Mfg. Company, 165 Broadway, New York; res., 39 Lewis St., Jamaica, N. Y.

NELSON, OSCAR W., Electrician, Boston City Club, Cor. Sommerset St. & Ashburton Place; res., 37 St. Albans Road, Boston, Mass.

NEPAGE, J. F., President, NePage, McKenny Co., Armour Bldg., Seattle, Wash.

NIXON, RICHARD OSCAR, Engineering Assistant, Philadelphia Rapid Transit Company, 820 Dauphin St., Philadelphia, Pa.

NOERR, LEONARD, Contracting Engineer, Suva, Fiji, Fiji Islands.

O'CONNOR, JOSEPH HUGH, Radio Operator, Fairfield Air Intermediate Depot, Fairfield, Ohio.

OJILVIE, HAROLD E., Electrical Engineer; Victorian Government Railways, Melbourne, res., 37 Spray Street, Elwood, Victoria, Australia.

PAWLING, RICHARD LEE, Salt River Valley Water User's Association; res., Lakeside Club, Roosevelt, Ariz.

QUERMANN, GEORGE HERMANN, Division Plant Superintendent, American Tel. & Tel. Company, 823 Boatmen's Bank Bldg., St. Louis, Mo.

RALPH, ARTHUR J., Technician, Electrical Engineering Laboratory, Yale University, New Haven; res., 3656 Whitney Ave., Mt. Carmel, Conn.

RAU, DAVID SOLIS, Student Engineer, Radio Corporation of America, Port Jefferson, L. I., N. Y.

ROSENKRANZ, CHARLES, Electrical Draftsman, Brooklyn Edison Company, 360 Pearl St.; res., 142 Floyd St., Brooklyn, N. Y.

SCHIMPFF, OSCAR JOSEPH, Engineer, Richard A. Wright, 37 W. 39th St., New York, N. Y.; res., 15 Edward St., Ridgewood, N. J.

SCHINDHELM, EDWARD HENRY, Electrical Contractor, 35 St. Johns Place, Stamford, Conn.

SCHMIDT, CHESTER J., Electrician, Heil Packing Company, 2216 LaSalle St.; res., 3336 Pennsylvania Ave., St. Louis, Mo.

SCHREGARDUS, WILLIAM F., Supervisor of Plant Methods & Results, Southwestern Bell Telephone Company, 955 Boatmen's Bank Bldg., St. Louis, Mo.

SCHWARTZ, DAVID L., 207 W. 118th St., New York, N. Y.

SEKI, RIUICHI, Electrical Engineer, The Radio Electric Power Company, Nagoya; res., 517 Nishi-Okubo, Tokio, Japan.

SHIELD, JOHN, Assistant Cable Engineer, Northern Electric Company, Ltd.; res., 79 Rozel St., Montreal, Que.

SIEDLER, CHARLES P., Engineering Dept., Western Union Telegraph Company, 195 Broadway, New York, N. Y.; res., 49 Church St., Montclair, N. J.

SKARBOVIK, BJARNE JOHANNES, Mexican Light & Power Company; Legacion de Noruega, Marsella No. 34, Mexico, D. F., Mex.

TAGGART, DAWSON M., Western Division Test Engineer, Western Electric Co., Chicago, Ill.; res., 231 Henry Bldg., Seattle, Wash.

TAKENONCHI, TAKASHI, Electrical Engineer, Daido Denryoku Kabushiki Kaisha, Nagoya, Japan.

*TALBOT, JOHN COFFIN, Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.; res., 14 Hillside Ave., Glen Ridge, N. J.

TAYLOR, WILLIAM ORFORD, Sales Manager, Power Apparatus Division, Northern Electric Co., Ltd.; res., 151 Percival Ave., Montreal, West Que.

TEBERG, ERNEST J., President & General Manager, Pembina Light & Power Company, Pembina, N. D.

*TISNE, ROLAND DAVID, 503 Cortland Ave., San Francisco, Calif.

VAN ALLEN, LANSING EDWIN, Engineer, Switchboard Dept., General Electric Company; res., 25 Forest Road, Schenectady, N. Y.

WALLBRECHT, CLAUD ALFRED, Electrical Superintendent, Penna. New Jersey Ry. Co., West Hanover St., Trenton, N. J.

WEAR, RALPH HEATON, Electrical Engineer, National Electrical & Engineering Co., Ltd.; res., 75 Queen St., Christchurch, N. Z.

*WEHLE, ARTHUR HENRY, Sales Engineer, Long Island Electric Service Company, 58 Sutphin Blvd.; res., 112 Grand Ave., Jamaica, N. Y.

WILLIAMS, CHARLES EWART, Radio Laboratorian, Navy Yard, Puget Sound, Bremerton; res., 8326 13th Ave., N. W. Seattle, Wash.

WILLIS, CLODIUS HARRIS, Lignum, Va.

WINTERSTEENE, GUY H., Electrician, Ohio Public Service Company; res., 1042 S. Linden Ave., Alliance, Ohio.

Total 100.

*Formerly Enrolled Students.

ASSOCIATES REELECTED AUGUST 8, 1922

HIRES, J. EDGAR, President, Automatic Machinery & Equipment Co.; Vice-Pres., Charles E. Hires Co., 1110 Land Title Bldg., Philadelphia; res., 206 S. 24th St., Langhorne, Pa.

SERVICE, JERRY H., Dean, Trade & Engineering Schools, Youngstown Institute of Technology; res., 1717 E. Madison Ave., Youngstown, Ohio.

ASSOCIATE REINSTATED AUGUST 8, 1922

BEALE, STANLEY HAROLD, Electrical Engineer, Aluminum Company of America, Massena, N. Y.

MEMBERS ELECTED AUGUST 8, 1922

ANSINGH, HERMAN KIMBALL, Switchboard Engineer, Westinghouse Elec. & Mfg. Company, E. Pittsburgh; res., Murrysville, Westmoreland Co., Pa.

BICKELHAUPT, CARROLL OWEN, Toll Traffic Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

FENNINGER, WILLIAM N., Educational Director, Brooklyn Edison Company, Inc., 360 Pearl St., Brooklyn; res., 8514 106th St., Richmond Hill, N. Y.

KARPOV, ALEXANDER V., Engineer, West Penn Power Company, 14 Wood St., Pittsburgh, Pa.

LEBLANC, AIME, Electrical Engineer, French Representative, Thomson-Houston Company; International General Electric Company, Schenectady, N. Y.

NORMAN, HORACE EDWARD, Superintendent, Campbell Electric Company; res., 530 Eastern Ave., Lynn, Mass.

SHIELDS, JAMES ROBERT, Electrical Engineer, Board of Education, 155 College St., Toronto, Ont.

STOKELY, RAY, Telephone Engineer, Western Electric Company, 463 West St., New York, N. Y.

STRIEBY, MAURICE EDWARD, Telephone Engineer, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

THELIN, VICTOR E., Engineer of Tests, Chicago Surface Lines, 105 S. La Salle St., Chicago, Ill.

VAN METER, JOSEPH LEROY, General Traffic Manager, American Tel. & Tel. Company, 195 Broadway, New York, N. Y.

VIPOND, WILLIAM STANLEY, Cable Engineer, Northern Electric Company, Ltd.; res., 192 St. Joseph Blvd., W., Montreal, Que.

ZWORYKIN, VLADIMIR KOSMA, Electrical Engineer, C. & C. Developing Company, 13th & Winchester Sts., Kansas City, Mo.

MEMBERS RE-ELECTED AUGUST 8, 1922

MANAHAN, R. H., City Electrician, City Hall, Los Angeles, Calif.

PYLE, CLARENCE G., Vice-President, Hobbs Storage Battery Company, 1231 S. Olive St., Los Angeles, Calif.

TRANSFERRED TO GRADE OF FELLOW, AUGUST 8, 1922

ARNOLD, J. LORING, Professor of Electrical Engineering, New York University, New York, N. Y.

FIELD, CROSBY, Engineering Manager, National Aniline & Chemical Co., Inc., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER, AUGUST 8, 1922

BEHRENS, EDWARD L., Muskegon, Mich.

BILLS, FRANK B., District Superintendent, Kinloch Long Distance Telephone Co., St. Louis, Mo.

BISCHOFF, LOUIS G., Transmission & Protection Engineer, Indiana Bell Telephone Co., Indianapolis, Ind.

CALDERWOOD, HUGH A., Professor of Electrical Equipment—Department Head, Carnegie Institute of Technology, Pittsburgh, Pa.

CURTIS, GEORGE S., Assistant Division Supt., Public Service Electric Co., Paterson, N. J.

EMERSON, CHARLES W., JR., General Foreman, Meter & Test Dept., United Electric Light & Power Co., New York, N. Y.

FERRARI, CHARLES, Technical Manager, Societe Meridionale di Elettricita, Naples, Italy.

FURNAS, W. C., Assistant Superintendent, Electrical Dept., Allis-Chalmers Mfg. Co., West Allis, Wis.

FUSSELL, LEWIS, In charge of Engineering Department, Swarthmore College, Swarthmore, Pa.

HORLE, LAWRENCE C. F., Consulting Electrical Engineer, New York, N. Y.

KELLY, JOSEPH T., JR., Directing Engineer, Foreign Trade Department, Ohio Brass Company, Paris, France.

HIGMAN, H. LAWTON, Divisional Maintenance Supt., Ebro Power Co., Barcelona, Spain.

RAMEY, BLAINE B., Section Engineer, Westinghouse Electric & Mfg. Co., East Springfield Plant, Springfield, Mass.

UHL, ARTHUR W., Experimental Electrical Engineer, Ford Instrument Co., Inc., New York, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held August 4, 1922, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

CRAWFORD, MAGNUS T., Supt. of Distribution, Puget Sound Power & Light Co., Seattle, Wash.

WEBER, CLIFFORD A. M., Engineer in General Charge, Small Motor Engineering Dept., Westinghouse Electric & Mfg. Co., Springfield, Mass.

To Grade of Member

BISHOP, WILLIS D., Sales Manager, Power Switchboard Division, Northern Electric Co., Ltd., Montreal, Canada.

CANN, JOHN O. G., Chief Engineer, Marconi Wireless Tel. Co. of Canada, Ltd., Montreal, Canada.

DIXON, AMOS F., Telephone Systems Engineer, Western Electric Co., New York, N. Y.

GODSHO, ALBERT P., Assistant Engineer, Bell Telephone Co. of Penna., Philadelphia, Pa.

KELLY, JOHN A., Chief Engineer, Elec. Construction Dept., Dingle Clark Co., Cleveland, O.

LOVELL, WILLIAM V., Assistant Engineer, National Electric Light Ass'n., New York, N. Y.

MAHONEY, FRANCIS W., Electrical Engineer, Densmore & LeClear, Boston, Mass.

ROSE, ARTHUR F., Electrical Engineer, American Tel. & Tel. Co., New York, N. Y.

WOODBURY, FRED P., Meter & Test Dept., United Electric Light & Power Co., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1922.

Ackerman, Roger O., Schenectady, N. Y.
Adler, Charles Jr., Baltimore, Md.
Anderson, Edward T., Rock Island, Ill.
Anderson, Gordon R., Indianapolis, Ind.
Baker, Edward E., Brooklyn, N. Y.
Barnard, Robert B., Seattle, Wash.
Barrett, William R., Salt Lake City, Utah
Bedorf, Albert Fred, Pittsburgh, Pa.
Borden, Douglas C., Toronto, Ont.
Bouchard, Marion J., Washington, D. C.
Boucher, James F., Smoky Falls, Ont.
Bowley, Joseph W., Reading, Pa.
Brokaw, James B., La Grande, Ore.
Conkling, DeWitt C., Elmhurst, L. I., N. Y.
Coy, J. Almon, New York, N. Y.
Cree, George G., Schenectady, N. Y.
Crook, Robert A., San Francisco, Calif.
Cuddohy, James W., Grand Rapids, Mich.
Cumming, Kenneth N., Marion, Mass.
Davis, John E., Pittsbugh, Pa.
Delany, James H., S. Orange, N. J.
deNagy, Ervin A., New York, N. Y.
De Sellem, George W., Portland, Ore.
Dodds, William C., Pittsburgh, Pa.
Dominquez, Raul Campos, Mexico City, Mex.
Elliott, John L., Albany, Ore.
Foust, Charles A., Glendale, L. I.
Funston, J. Edward, Pittsburgh, Pa.
Hayes, Ralph S., Eastport, Me.
Houghton, Albin J., Jr., Los Angeles, Calif.
Hunt, William V., (Member) Vancouver, B. C.
Jonas, Emil J., (Member), Cincinnati, Ohio
Ledford, Harris A., Harrisburg, Pa.
Lowell, Dwight E., Philadelphia, Pa.
Mangione, John, New York, N. Y.
Manny, Henry H., Seattle, Wash.
McFarland, Hugh B., Lennox, S. Dak.
Moore, Lawrence N., Columbus, Ohio
McCue, Russell, New York, N. Y.
Osterle, William H., Xenia, Ohio
Parker, Merton C., Portland, Ore.
Pearl, Eugene S., Passaic, N. J.
Quantrille, Clinton A., Washington, D. C.
Qvist, Oscar, Chicago, Ill.
Reid, Harry, Indianapolis, Ind.
Requa, William A., Rochester, N. Y.
Sharp, Cecil B., Pittsburgh, Pa.
Sinnott, Joseph D., Spokane, Wash.
Smith, Lyle W., Schenectady, N. Y.
Strong, Thomas Foster, Preston, Idaho
Vaughan, George W., Mt. Vernon, N. Y.
Vere, Fernand, New York, N. Y.
Wald, Albert, New York, N. Y.
Waldmann, Charles, New York, N. Y.
Westcott, Philip S., Milwaukee, Wis.
Total 55.

Foreign

Boynton, Kenneth K., Yokohama, Japan
Carlson, Victor H., Tocopilla, Chile, S. A.
Dunsheath, Percy (Member), N. Woolwich, London, Eng.
Grant, John A., Kew, Victoria, Aus.
Holly, Harold C., Yokohama, Japan
Mazen, Natalis, (Fellow), Paris, France
Meyers, Frank P., Te Awamutu, N. Z.
Townsend, Leroy S., Ancon, C. Z.
Total 8.

STUDENTS ENROLLED AUGUST 8, 1922

15309 Smith, Philip C., Mass. Institute of Tech.
15310 Thwaite, Walter E., Jr., Cooper Union
15311 Lawrence, Henry J., Lowell Institute
15312 Triggs, Ed. O., Marquette University
15313 Maxwell, Howard H., Toronto Central Technical School
15314 Warford, Henry W., Tri-State College of Engineering
15315 Zeiger, Henry, Mass Institute of Tech.
15316 Hardner, Francis J., New York Electrical School
15317 McCullough, M. B., University of Utah
15318 Gerofski, Irvin, Mass. Inst. of Technology
15319 Harper, Marvin H., Emory University
15320 Allen, Harold P., Clarkson College of Technology
15321 Reed, Calvin F., Ohio State University
15322 Romanoff, Frank, Lewis Institute
15323 Keenan, John S., Mass. Institute of Tech.
15324 Tseng, Hsin-Ming, Rensselaer Poly. Inst.
15325 Primiano, Alfred J., New York Electrical School
15326 Price, Arthur V., University of Toronto
15327 Richards, Arthur H., School of Engineering of Milwaukee
15328 Smith, Louis E., School of Engineering of Milwaukee
15329 Holleman, Elwood, New York Electrical School
Total 21.

Officers A. I. E. E. 1922-1923

PRESIDENT.

(Term expires July 31, 1923)
FRANK B. JEWETT

JUNIOR PAST-PRESIDENTS

(Term expires July 31, 1923)
A. W. BERRESFORD

(Term expires July 31, 1924)
WILLIAM McCLELLAN

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(Terms expire July 31, 1923)
N. W. STORER
C. G. ADSIT
F. W. SPRINGER
ROBERT SIBLEY
F. R. EWART

(Terms expire July 31, 1924)
G. FACCIOLI
W. I. SLICHTER
R. F. SCHUCHARDT
H. W. EALES
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MANAGERS

(Terms expire July 31, 1923)
L. E. IMLAY
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L. F. MOREHOUSE

(Terms expire July 31, 1924)
HAROLD B. SMITH
JAMES F. LINCOLN
E. B. CRAFT

(Terms expire July 31, 1925)
R. B. WILLIAMSON
A. G. PIERCE
HARLAN A PRATT

(Terms expire July 31, 1926)
H. M. HOBART
ERNEST LUNN
G. L. KNIGHT

TREASURER | SECRETARY

(Terms expire July 31, 1923)
GEORGE A HAMILTON | F. L. HUTCHINSON

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GENERAL COUNSEL

PARKER & AARON,
66 Broad Street, New York.

PAST-PRESIDENTS—1884-1922

*Norvin Green, 1884-5-6.
*Franklin L. Pope, 1886-7.
T. Commerford Martin, 1887-8.
Edward Weston, 1888-9.
Elihu Thomson, 1889-90.
*William A. Anthony, 1890-91.
*Alexander Graham Bell, 1891-2.
Frank Julian Sprague, 1892-3.
*Edwin J. Houston, 1893-4-5.
*Louis Duncan, 1895-6-7.
*Francis Bacon Crocker, 1897-8.
A. E. Kennelly, 1898-1900.
Carl Hering, 1900-1.
Charles P. Steinmetz, 1901-2.
Charles F. Scott, 1902-3.
Bion J. Arnold, 1903-4.
John W. Lieb, 1904-5.
Schuyler Skaats Wheeler, 1905-6.
*Samuel Sheldon, 1906-7.
*Henry G. Stott, 1907-8.
Louis A. Ferguson, 1908-9.
Lewis B. Stillwell, 1909-10.
Dugald C. Jackson, 1910-11.
Gano Dunn, 1911-12.
Ralph D. Mershon, 1912-13.
C. O. Mailloux, 1913-14.
Paul M. Lincoln, 1914-15.
John J. Carty, 1915-16.
H. W. Buck, 1916-17.
E. W. Rice, Jr., 1917-18.
Comfort A. Adams, 1918-19.
Calvert Townley, 1919-20.
A. W. Berresford, 1920-21.
William McClellan, 1921-22.

*Deceased.

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Chairman of Committee on Coordination of Institute Activities.
Chairmen of Technical Committees.
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W. I. Slichter, Chairman, Columbia University, New York
E. E. F. Creighton, F. L. Hutchinson, Donald McNicol.
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BOARD OF EXAMINERS

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Philander Betts, G. L. Knight, J. H. Morecroft,
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SECTIONS COMMITTEE

A. W. Berresford, Chairman, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
C. F. Harding, Vice-Chairman
John B. Fisken, H. B. Smith, J. Lloyd Wayne.
Chairmen of all Sections.

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C. F. Harding, Chairman, Purdue University, Lafayette, Ind.
A. C. Lanier, C. E. Magnusson, Harold B. Smith.
Charles F. Scott,

MEMBERSHIP COMMITTEE

R. B. Howland, Chairman, 125 E. 46th St., New York.
W. L. Amos, J. E. MacDonald, M. E. Skinner,
R. L. Dodd, G. H. Middlemiss J. L. Woodress.
F. L. Kemp, H. T. Plumb,

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H. W. Buck, Chairman, 49 Wall Street, New York.
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William McClellan,

COMMITTEE ON CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT

Schuyler S. Wheeler, Chairman, Crocker-Wheeler Co., Ampere, N. J.
C. A. Adams, G. Faccioli, George F. Sever,
A. H. Babcock, J. W. Lieb, H. S. Wynkoop.

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H. B. Gear, Chairman, 72 West Adams St., Chicago, Ill.
H. C. Cushing, M. G. Lloyd, Farley Osgood,
J. C. Forsyth, Ernest Lunn, H. R. Sargent,
H. O. Lacount, Wills Maclachlan, A. M. Schoen,
Johnston Livingston, R. W. E. Moore, H. S. Warren.
H. N. Muller,

STANDARDS COMMITTEE

Harold Pender, Chairman, University of Pennsylvania, Philadelphia, Pa.
H. S. Osborne, Secretary, 195 Broadway, New York
W. A. Del Mar, A. M. MacCutcheon, F. D. Newbury,
G. L. Knight J. F. Meyer, F. L. Rhodes,
H. A. Lardner, L. T. Robinson,
And the Chairmen of such working committees as may be appointed.

EDISON MEDAL COMMITTEE

Appointed by the President for term of five years.

(Term expires July 31, 1923)
Frederick Bedell, L. T. Robinson, Calvert Townley.
(Term expires July 31, 1924)
E.D.Adams, Chairman, H. H. Barnes, Jr., B. G. Lamme.
(Term expires July 31, 1925)
H. M. Byllesby, D. E. Drake, W. L. R. Emmet.
(Term expires July 31, 1926)
B. A. Behrend, John H. Finney, C. S. Ruffner.
(Term expires July 31, 1927)
Gano Dunn, F. A. Scheffler, W. R. Whitney.

Elected by the Board of Directors from its own membership for term of two years

(Term expires July 31, 1923)
A. W. Berresford, L. F. Morehouse, R. B. Williamson.
(Term expires July 31, 1924)
E. B. Craft, G. Faccioli, William McClellan.

Ex-Officio

Frank B. Jewett, President, George A. Hamilton, Treasurer,
F. L. Hutchinson, Secretary.

RESEARCH COMMITTEE

J. B. Whitehead, Chairman, Johns Hopkins University, Baltimore, Md.
B. A. Behrend, W. P. Dobson, M. G. Lloyd,
Edward Bennett, C. I. Hall, L. F. Morehouse,
F. S. Clark, L. A. Hawkins, G. W. Pierce,
E. H. Colpitts, D. C. Jackson, H. J. Ryan,
E. E. F. Creighton, A. E. Kennelly, C. H. Sharp,
W. A. Del Mar, J. R. Klumpp, C. E. Skinner.

TECHNICAL COMMITTEES

EDUCATIONAL

C. E. Magnusson, Chairman, University of Washington, Seattle, Wash.

W. C. Bauer, Edward Bennett, C. R. Dooley, Charles S. Howe, G. H. Pfeif, H. W. Price, Charles F. Scott, Harold B. Smith, W. L. Upson, J. B. Whitehead, W. E. Wickenden, Wm. R. Work.

ELECTRICAL MACHINERY

B. A. Behrend, Chairman, 85 Devonshire St., Boston, Mass.
A. S. McAllister, Secretary, 248 W. 76th St., New York.

B. L. Barns, R. E. Brown, James Burke, G. Faccioli, W. J. Foster, V. A. Fynn, David Hall, H. U. Hart, V. Karapetoff, P. M. Lincoln, H. P. Liversidge, F. D. Newbury, Philip Torchio, R. B. Williamson.

ELECTROCHEMISTRY AND ELECTROMETALLURGY

J. L. Yardley, Chairman, W. E. & M. Co., East Pittsburgh, Pa.

F. G. Clark, Saul Dushman, Carl Hering, L. E. Imlay, J. A. Seede, G. W. Vinal.

ELECTROPHYSICS

F. W. Peek, Jr., Chairman, General Electric Co., Pittsfield, Mass.

E. F. Burton, L. W. Chubb, J. C. Clark, C. P. Eldred, Charles Fortescue, Roy S. Glasgow, E. P. Hyde, J. H. Morecroft, Chester W. Rice, F. B. Silsbee, H. B. Smith, J. B. Whitehead.

INDUSTRIAL AND DOMESTIC POWER

H. P. Reed, Chairman, A. Kieckhefer Elevator Co., Milwaukee, Wis.
(Other members to be appointed.)

INSTRUMENTS AND MEASUREMENTS

A. F. Bang, P. A. Borden, W. M. Bradshaw, H. B. Brooks, F. P. Cox, E. D. Doyle, A. L. Ellis, F. V. Magalhaes, G. A. Sawin, Irving B. Smith, H. C. Snook, F. W. Springer, H. S. Vassar.

IRON AND STEEL INDUSTRY

E. S. Jefferies, Chairman, Steel Co. of Canada, Hamilton, Ont.
(Other members to be appointed.)

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NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Radio Telephone Equipment.—Bulletin 200-55-D. Headsets, loudspeakers, terminals, sockets and switches. Chas. Cory & Son, Inc., 183 Varick Street, New York.

Transformers.—Bulletin 111, Single-phase Transformers, 12 pp., Bulletin 112, Three-phase Transformers, 4 pp. Describe distribution and power transformers of the types mentioned. Kuhlman Electric Company, Bay City, Michigan.

Molding Presses.—Bulletin. Describes hydraulic hot and cold plate presses for molding bakelite, condensite and similar material. The Hydraulic Press Mfg. Co., Mount Gilead, Ohio.

Printing Press Control.—Bulletin 103, 32 pp. Illustrates and describes "Monitor" automatic equipment for the control of printing presses, binding and other shop auxiliary machinery. Monitor Controller Company, Baltimore, Md.

Line Material for Mines.—Catalog 6—M, 64 pp. Describes Westinghouse electric apparatus for use in mines. In addition to line material it contains much information about safety switches, mine locomotives, tapes, solders, etc. Westinghouse Electric & Mfg. Co., East Pittsburgh.

Dynamometer Chassis Test System.—Bulletin 48718, 8 pp. Describes the Sprague Electric Chassis Test System for automobile manufactures, service stations and public garages. This system secures the results of a road test without taking the car outside the building. Sprague Electric Works of G. E. Co., 527 West 34th St., New York.

Redmanol.—Booklet, 36 pp. Illustrates applications of Redmanol (a synthetic resin) in electrical and radio apparatus, and for many other purposes. Describes the process of hot and cold molding, and gives results of tensile, crushing, dielectric and heat tests of the molded and laminated product. Redmanol Chemical Products Co., 636 West 22nd St., Chicago.

Micarta Gears.—Folder 4453, "Quiet Running Gears," enumerates the points of superiority claimed for Micarta gears, such as quietness and durability, and other advantages to be derived from these non-metallic gears. Westinghouse Electric & Mfg. Co., East Pittsburgh.

NOTES OF THE INDUSTRY: NEW APPARATUS

Pure Carbon Company, Wellsville, N. Y.—Carbon Brushes. Announcement is made of the appointment of an Eastern representative, The Hoyt Equipment Co., 52 Vanderbilt Ave., New York.

Amplifying Transformer.—A new amplifying transformer for radio use is being produced by the Pacent Electric Company, 150 Nassau Street, New York. The new device occupies a space of only 1¾ by 1½ inches, and maximum amplification with the least possible distortion is claimed for it.

Ideal Electric & Mfg. Company, Mansfield, O.—Manufacturers of squirrel cage, direct-current and synchronous motors, a-c. and d-c. generators. This firm has appointed the Boustead Electric & Mfg. Co. Inc., Minneapolis, as Northwestern distributors of the Ideal products.

Canadian Brandes, Ltd. Radio Head Sets.—This Canadian plant of C. Brandes, Inc., New York was established recently, and Edgar Rypinski, formerly of the sales staff of the parent concern, placed in charge. C. Perkins, Ltd. of Montreal, have been appointed representatives of Canadian Brandes, Ltd.

Brush.—A new electro-graphitic brush known as "259" has been placed on the market by the National Carbon Co. Inc. adapted to a very wide range of voltages, current densities and speeds on undercut commutators of d-c. motors and generators, and on the d-c. side of rotary converters.

Johns-Pratt Company, Hartford, Conn.—Manufacturers of Noark fuses and protective devices, Vulcabeston packing and insulation and molded products. Arthur Ward Fox, formerly Secretary and Assistant Treasurer, has been elected to the office of Vice-President and General Manager of the Johns-Pratt Company. He has been associated with the firm for sixteen years. Beginning with the administration of Mr. Fox as Vice-President, all Johns-Pratt products will be marketed direct. Heretofore they have been sold through Johns-Manville, Inc.

Transformer.—A disconnecting type series-multiple transformer has been developed by the Kuhlman Electric Company, which embodies two new important features, in that it can be used under or above ground without impairment of efficiency, and disconnected and reconnected without splicing. Only three minutes is required to make or break the non-splice, water-tight connections, if necessary for testing or other purposes. If submerged in water, the transformer will operate indefinitely without damage, therefore it is not affected by moisture in manholes, at the base of light poles, or when buried without protection in the ground. The new type apparatus is described in Bulletin No. 113, issued by the Kuhlman Electric Company, Bay City, Michigan.

Electric Power Club Handbook.—1922 edition, 364 pp. The Electric Power Club has issued a new edition (14th) of its handbook, covering substantially all the standardization it has effected in the electric motors, motor pulleys, generators, transformers, electric tools, mining and industrial locomotives, control equipment, power switchboards and switching equipment manufactured in this country.

The handbook also contains definitions, symbols, general engineering recommendations and other information needed by users and purchasers of electric power apparatus and control equipment.

Single copies will be given without charge to consulting engineers, electric light and power companies, rated electrical contractors, and educators; otherwise the charge is fifty cents per copy. Requests should be directed to S. N. Clarkson, Executive Secretary, The Electric Power Club, Kirby Building, Cleveland, Ohio.

Report on Pyrene.—The Transit Commission has made public a report prepared by the Chief Executive Officer, General Lincoln C. Andrews, in respect to the causes and results of the electrical fire which occurred in the New York subway on July 6. Carbon tetrachloride fire extinguishers, made by the Pyrene Manufacturing Company, Newark, N. J. were employed in putting out the flames and certain city officials laid the cause of semi-suffocation of passengers to the fumes created by the use of such extinguishers. That part of the report relating to this phase of the accident, however, establishes that any vapors which may have been formed, contributed but little to the discomfort of the passengers, which was mainly due to inhaling the smoke from burning insulation—, rubber, paint and varnish, and that there was no evidence of poisonous gas generated through the use of Pyrene.

The report concludes with the statement that a thorough search for a suitable substitute for carbon tetrachloride as a fire extinguisher in similar circumstances, had disclosed none as good or better.